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RESEARCH MEMORANDUM

THE EFFECTS OF FENCES ON THE HIGH-SPEED LONGITUDINAL STABILITY OF A SWEPT-WING AIRPLANE

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THE EFFECTS OF FENCES ON THE HIGH-SPEED LONGITUDINAL STABILITY OF A SWEPT-WING AIRPLANE

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SUMMARY

A series of fence installations have been tested on a swept-wing jet airplane to determine their effects on the longitudinal instability, or "pitch-up," encountered in high-speed maneuvering flight. Longitudinal-stability measurements were made at Mach numbers between 0.80 and 0.93 with nine fence configurations which varied in chordwise extent and spanwise position.

The longitudinal-stability characteristics of the airplane were not significantly altered by any of the fence installations at Mach numbers below 0.87; however, between Mach numbers of 0.87 and 0.93, several of the fence configurations were effective in delaying the pitch-up to higher normal-force coefficients. The maximum increase in the stable normal-force coefficient range was from 0.32 to 0.50 at a Mach number of 0.92. Other high-speed longitudinal- and lateral-stability characteristics were not appreciably modified. At low speeds, several of the fence installations were effective in improving the stalling characteristics of the airplane in the landing configuration with wing leading-edge slats locked closed.

INTRODUCTION

The F-86A airplane, in common with other swept-wing aircraft, exhibits a longitudinal instability, or pitch-up, at moderate lift coefficients which limits its high-speed maneuverability (ref. 1). This problem is particularly serious at Mach numbers between 0.80 and 0.95. Below this speed range the pitch-up is relatively mild and controllable, while above these speeds, the airplane is stable throughout the attainable range of lift coefficients. The results of reference 1 revealed the pitch-up to be due to a reduction in wing-fuselage stability which results from stalling at the wing tips.

A series of modifications intended to remedy this and related high-speed stability problems was investigated and reported in reference 2. Included among the modifications tested was a multiple-fence installation which was effective in increasing the stable lift-coefficient range above a Mach number of 0.87. In view of these results, the program was expanded to include tests of a systematic series of fence configurations in an effort to obtain increased benefits. A secondary objective of the subject investigation, in common with the studies of previous modifications, was to obtain a clearer understanding of the flow phenomena responsible for various stability changes.

This report presents the results of tests of a series of fence configurations varying in number of fences, chordwise extent, and spanwise position.

NOTATION

A_z	ratio of net aerodynamic force normal to the airplane longitudinal axis to the weight of the airplane (positive when directed upward)
$C_{D_{C_N}=0.15}$	airplane drag coefficient, $\frac{D}{qS}$, at an airplane normal-force coefficient of 0.15
C_N	airplane normal-force coefficient, $\frac{WA_z}{qS}$
D	airplane drag, lb
M	free-stream Mach number
S	wing area, sq ft
W	airplane weight, lb
b	wing span, ft
c	local wing chord, ft
$\bar{c}$	mean aerodynamic chord, ft
q	free-stream dynamic pressure, lb/sq ft
δ_e	elevator angle, measured normal to hinge line, deg

EQUIPMENT AND TESTS

The test airplane was the same as that of references 1 and 2, a North American F-86A-5, USAF No. 48-291. A photograph of the unmodified test airplane is presented in figure 1. Geometric details and a two-view drawing are given in table I and figure 2, respectively.

Standard NACA instruments and an 18-channel oscillograph were used to record all measured quantities. Horizontal-tail loads used in the determination of wing-fuselage pitching moments were obtained from strain-gage measurements of the loads at the three pin-joined fittings mounting the horizontal tail to the fuselage. Airplane drag was measured by use of the method and equipment described in reference 2.

The investigation included tests of the airplane unmodified and with nine individual fence configurations shown in table II. Five of these, configurations A through E, employed a multiple installation (three fences on each wing) and varied in chordwise extent. The fence locations were at 46, 63, and 80 percent of the wing semispan. Each of the fences of configuration A was tested individually to determine the effect of spanwise location. These configurations are designated A_1, A_2, and A_3. One additional installation, configuration F, simulated that in use on the MIG-15 airplane. Photographs of a typical fence installation are shown in figure 3, and geometric details of the basic fence configurations are presented in figure 4.

All tests of the high-speed longitudinal stability of the airplane were conducted at a nominal altitude of 35,000 feet. The wing loading averaged 43 pounds per square foot, and the center-of-gravity position was at 22.5 percent of the wing mean aerodynamic chord.

Stability measurements were taken in constant Mach number wind-up, or gradually tightening, turns. Due to variations of stability parameters with speed in the Mach number range between 0.89 and 0.94, it was essential that data be used for only those maneuvers in which the Mach number varied no more than 0.01. Each configuration was also flown in dives to speeds above a Mach number of 1.0 in order to investigate any effects of the fences on the longitudinal and lateral trim changes noted on the basic airplane at transonic speeds. Low-speed stalls were performed in order to evaluate the effectiveness of fences in producing satisfactory stalling characteristics in the landing configuration with the leading-edge slats retracted. No measurements were taken during these stalls, but pilots' evaluation reports were made.

CORRECTIONS

Pitching-moment data and elevator angles presented for normal-force coefficients in the pitch-up range were corrected for the effects of pitching acceleration. The correction to the tail load was computed as the additional load at the tail required to reduce the pitching acceleration to zero. This incremental load, in terms of pitching-moment coefficient, was used together with the elevator-effectiveness data of reference 1 to determine an approximate trim elevator angle.

Below the pitch-up, these corrections were considered negligible and were not applied. Measured tail loads were also corrected for inertia effects.

ACCURACY

The accuracy of the measured variation of tail loads during any single maneuver is estimated to be of the order of ±150 pounds. However, due to the difficulty of detecting zero shifts in the instrumentation during flight, the uncertainty in the absolute value of the measured load is considered to be somewhat greater. The value of pitching-moment coefficient corresponding to ±150 pounds tail load at an altitude of 35,000 feet and a Mach number of 0.88 is ±0.004. The uncertainty in determination of normal-force coefficient is ±0.02, and elevator angle measurements are accurate to $\pm 1/4^\circ$. The values of the slopes $dC_{m_{w+f}}/dC_N$ and $d\delta_e/dC_N$ are subject to a small variation (less than ±1 percent of the M.A.C.) in the center-of-gravity position because of fuel usage during flight.

The uncertainty in the absolute values of measured drag has not been defined, but measurements of drag-coefficient increments are considered to be accurate within ±0.001.

RESULTS AND DISCUSSION

Longitudinal Stability

The results of the investigation of reference 1, which define the high-speed longitudinal-stability characteristics of the unmodified test airplane, show the normal-force coefficient for stability to be limited to 0.5 at Mach numbers from 0.80 to 0.86. As Mach number is increased, the normal-force coefficient for the onset of instability decreases, reaching a minimum value of about 0.3 at a Mach number of 0.92. This instability, or pitch-up, was demonstrated to be directly attributable to changes in wing-fuselage stability resulting from loss of lift at the wing tips. The effects of a number of fence configurations on these characteristics are presented in figures 5 through 10.

Effects of variations in chordwise extent of fences.- The effects on the longitudinal stability of the test airplane of several fence configurations which varied in chordwise extent are shown in figures 5 through 7. Variations of wing-fuselage pitching moment, $C_{m_{w+f}}$, with airplane normal-force coefficient, C_N, at several Mach numbers between 0.80 and 0.93 are presented for configurations A through E in figure 5.

As an indication of the stability of the complete airplane, the corresponding variation in elevator angle, δ_e, is shown in figure 6. Included in these figures for comparison are the characteristics of the unmodified airplane. Configurations A and B are shown in figures 5(a) and 5(b) to be effective in delaying the wing-fuselage instability at Mach numbers above 0.88, but below this speed they do not appear to alter appreciably the stability characteristics. The maximum effectiveness of these fences, as with those of reference 2, was obtained at a Mach number of about 0.92, where the stable normal-force-coefficient range was extended from 0.3 to 0.5. Pitch-up of the airplane as indicated in figure 6 by the sudden severe reduction or reversal in the slope $d\delta_e/dC_N$ is seen to occur simultaneously with the rapid decrease in wing-fuselage stability. Thus, it appears that the pitch-up remains a direct result of the wing-fuselage instability as was shown in reference 1.

Configuration C, fences aft of the 50-percent chord line (figs. 5(c) and 6(c)), was comparatively ineffective in delaying the instability. The results of the investigation reported in reference 3 indicated a similar lack of effectiveness of trailing-edge fences when compared to fences extending forward of midchord. Although the wing of the subject investigation differs considerably in geometry from that of reference 3, the separation phenomenon involved, which is to be the subject of later discussion, is quite similar.

The failure of configuration D, figures 5(d) and 6(d), to significantly alter the stability characteristics of the airplane is surprising since it differed from configuration A only in respect to an extension of the fences around the wing leading edge. These results are even more anomalous in view of the apparent effectiveness, at a Mach number of 0.91, of fence configuration E (figs. 5(e) and 6(e)), which also incorporates the extension. Due to the limited availability of the test airplane and the lack of any indication that either of these installations was more beneficial than configuration A, further tests directed toward clarifying these results were not performed. The effects of the fence extension at high speeds should be investigated since a number of fence installations which are at present being used to improve the low-speed stalling characteristics of swept-wing airplanes incorporate this feature.

A series of pitch-up boundaries are presented in figure 7 as a summary of the results obtained with fences varying in chordwise extent. These boundaries were determined from time-history records of pitching velocity, normal acceleration, and elevator angle, and define the normal-force coefficient at which there occurs a sudden increase in pitching velocity and normal acceleration independent of an increase in control deflection. It should be pointed out that although these boundaries define the limit of "stick-fixed" airplane stability, reductions in the slopes $dC_{m_{w+f}}/dC_N$ and $d\delta_e/dC_N$ at normal-force coefficients below the pitch-up, as indicated for several of the configurations at the highest Mach numbers, might be considered objectionable.

Effects of variations in spanwise position.- The high-speed longitudinal-stability characteristics of the test airplane as affected by the spanwise location of a single full-chord fence of the same type as used with configuration A are presented in figures 8 and 9. Variations of wing-fuselage pitching-moment coefficient and elevator angle with normal-force coefficient are shown for several Mach numbers.

A single fence at 63-percent semispan, configuration A_2, was found to be nearly as effective as the multiple-fence installation, A. The outboard fence, A_3, located at 80-percent semispan is shown to be about half as effective as A_2; whereas the inboard fence A_1 produced little change in the stability characteristics of the airplane.

Stability boundaries for the test airplane with fences A_1, A_2, and A_3 are compared with those for configuration A and the basic airplane in figure 10. Also included for comparison is a stability boundary of the airplane with an additional fence installation having full-chord fences at 29 and 46 percent of the wing semispan. This configuration, which was similar to that used on the MIG-15 airplane, is seen to be no more effective than the single inboard fence.

Flow Phenomena

Within the Mach number range of the subject investigation, photographs of tufts on the wing surface have indicated that on the unmodified wing the separation pattern preceding and during the pitch-up varies considerably with Mach number. At Mach numbers between 0.80 and 0.86, the first indications of flow separation on the wing appear on the outer portion of the panel at midchord at a normal-force coefficient of about 0.40. This separation spreads very rapidly at a normal-force coefficient of about 0.50, resulting in an abrupt loss of lift at the wing tips. Sketches showing various stages of this type of separation pattern are presented in figure 11(a). Although there are indications of a thickened boundary layer with outward flow at the trailing edge prior to the pitch-up, it is apparent that at these speeds the stall does not originate in this region.

As the Mach number is increased beyond 0.86, increased outflow in the boundary layer is noted at the trailing edge of the outer portion of the wing, even at low values of normal-force coefficient. At higher normal-force coefficients, the flow in this region becomes separated, the area of separation increasing gradually with increasing angle of attack. Photographs obtained by the flight shadowgraph technique of reference 4 have indicated the presence of a strong shock wave forward of this region which appears to originate at the wing root near the trailing edge and extends outboard over the wing tip. It is probable that this shock wave either induces or seriously aggravates the flow separation at the trailing edge. Sketches illustrating the development of this type of separation pattern are shown in figure 11(b). The pitch-up coincides with what appears as a rapid spreading of the separation forward and inboard.

The addition of fences to the wing of the test airplane made no marked change in the separation pattern other than to delay to higher normal-force coefficients the spread of separation at Mach numbers above 0.86. At normal-force coefficients below that for the instability, there were indications of tuft agitation immediately inboard of each fence, indicating the presence of unsteady flow in these regions.

The failure of any of the fences to raise the pitch-up boundary above a normal-force coefficient of 0.5 at the higher Mach numbers suggests that the wing remains subject to the same type of separation as at Mach numbers of about 0.8.

Buffeting and Wing Dropping

Below a Mach number of 0.90, the buffet boundary of the unmodified airplane corresponds, in general, to the stability boundary. As the Mach number is increased above 0.90, very mild buffeting is noted over a widening range of normal-force coefficients prior to the pitch-up and appears to coincide with the occurrence of shock-induced separation on the outer portions of the wing near the trailing edge. These buffet characteristics were not noticeably changed with the addition of any of the fence configurations. The additional stable normal-force-coefficient range attributable to the fences was marked by mild buffeting similar to that normally noticed just prior to the instability, heavy buffeting being delayed until after the occurrence of the pitch-up.

Reference 2 reported the occurrence of a low-lift lateral-trim change between Mach numbers of 0.94 and 1.00 which was referred to as a "wing-dropping" tendency. This effect is associated with a reversal in aileron hinge moment and effectiveness at moderately small deflections. A decrease in this rolling tendency was effected with installations of vortex generators which apparently reduced the amount of flow separation over the ailerons. It was expected, therefore, that fences extending over the full chord of the wing might produce a similar improvement. However, pilots' reports indicated that none of the fence installations tested had a noticeable effect on the wing-dropping characteristics. Measurements of aileron deflections required to trim the airplane confirmed this conclusion.

Drag

A comparison of the drag of the airplane with fence configuration D with that of the basic airplane (ref. 2) is shown in figure 12 for a normal-force coefficient of 0.15. The increment in drag coefficient due to the fences was about 0.0010 at a Mach number of 0.80 and increased to 0.0025 at a Mach number of 0.91. It should be noted that these values represent the drag of the most extensive fence configuration tested. It is assumed that the drag due to the other configurations was proportionally less. Also, it is believed that cleaner, more permanent installations might result in a smaller drag increment.

Low-Speed Stalls

The basic airplane with the wing leading-edge slats locked closed, flaps and landing gear extended, exhibited a low-speed stall characterized by unsatisfactory stall warning, a mild pitch-up, and an abrupt roll-off. Pilots' comments indicated that several of the fence configurations noticeably improved these characteristics. All the multiple-fence installations which included fences on the forward 50 percent of the chord were effective to some extent in improving the lateral controllability at the stall. The most improved stalling characteristics with respect to stall-warning buffet and lateral controllability were produced by configurations E and F. Two of the single fences, configurations A_1 and A_2, also afforded improved lateral-control characteristics in the stall.

CONCLUSIONS

An investigation of the effects of a series of fence installations on the high-speed longitudinal-stability characteristics of a swept-wing airplane has indicated:

1. Below a Mach number of 0.87, at which speeds the tip-stall appeared to be the result of separation originating at midchord of the outboard portion of the wing, no fences tested were effective in delaying the pitch-up.

2. In the Mach number range between 0.87 and 0.93, at which speeds the instability occurs as the result of separation at the trailing edge, several arrangements of fences were effective in delaying the pitch-up to higher normal-force coefficients.

3. In general, the fences which were effective in delaying the pitch-up extended forward of midchord.

4. A single fence, located at 63 percent of the wing semispan, approached in effectiveness the best multiple-fence installation tested.

5. The buffeting and wing-dropping characteristics of the airplane at high Mach numbers were not significantly altered by any of the fence installations.

6. The lateral controllability of the airplane in low-speed stalls with slats locked closed was improved most by inboard fences extending over the forward half of the wing chord.

Ames Aeronautical Laboratory
National Advisory Committee for Aeronautics
Moffett Field, Calif., June 23, 1953

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1. Anderson, Seth B., and Bray, Richard S.: A Flight Evaluation of the Longitudinal Stability Characteristics Associated with the Pitch-Up of a Swept-Wing Airplane in Maneuvering Flight at Transonic Speeds. NACA RM A51I12, 1951.

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3. Edwards, George G., Tinling, Bruce E., and Ackerman, Arthur C.: The Longitudinal Characteristics at Mach Numbers Up to 0.92 of a Cambered and Twisted Wing Having 40° of Sweepback and an Aspect Ratio of 10. NACA RM A52F18, 1952.

4. Cooper, George E., and Rathert, George A., Jr.: Visual Observations of the Shock Wave in Flight. NACA RM A8C25, 1948.

TABLE I.- DESCRIPTION OF TEST AIRPLANE

Wing	
Total wing area (including flaps, slats, and 49.92 sq ft covered by fuselage)	287.90 sq ft
Span	37.12 ft
Aspect ratio	4.79
Taper ratio	0.51
Mean aerodynamic chord (wing station 98.7 in.)	8.08 ft
Dihedral angle	3.0°
Sweepback of 0.25-chord line	$35^\circ 14'$
Sweepback of leading edge	$37^\circ 44'$
Aerodynamic and geometric twist	2.0°
Root airfoil section (normal to 0.25-chord line)	NACA 0012-64 (modified)
Tip airfoil section (normal to 0.25-chord line)	NACA 0011-64 (modified)
Ailerons	
Total area	37.20 sq ft
Span	9.18 ft
Chord (average)	2.03 ft
Horizontal tail	
Total area (including 1.20 sq ft covered by vertical tail	34.99 sq ft
Span	12.75 ft
Aspect ratio	4.65
Taper ratio	0.45
Dihedral angle	10.0°
Root chord (horizontal-tail station 0)	3.79 ft
Tip chord, equivalent (horizontal-tail station 76.68 in.)	1.74 ft
Mean aerodynamic chord (horizontal-tail station 33.54 in.)	2.89 ft
Sweepback of 0.25-chord line	$34^\circ 35'$
Airfoil section (parallel to center line)	NACA 0010-64
Maximum stabilizer deflection	$+1^\circ$ up, -10° down
Elevator	
Area (including tabs and excluding balance area forward of hinge line)	10.13 sq ft
Span, each	5.77 ft
Chord, inboard (equivalent horizontal-tail station 6.92 in.)	1.19 ft
Chord, outboard (theoretical, horizontal-tail station 76.18 in.)	0.57 ft
Maximum elevator deflection	35° up, 17.5° down
Boost	Hydraulic

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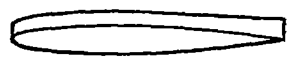
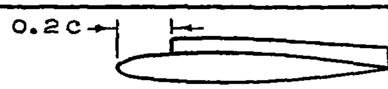
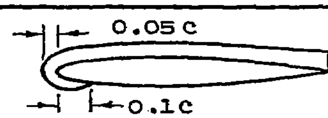
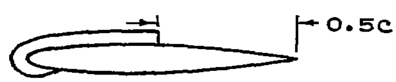
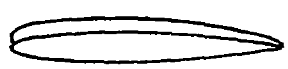
TABLE II.- DESIGNATIONS OF FENCE CONFIGURATIONS

Configurations		Spanwise location, percent semispan
A		46, 63, 80
A_1		46
A_2		63
A_3		80
B		46, 63, 80
C		
D		
E		
F		29, 46

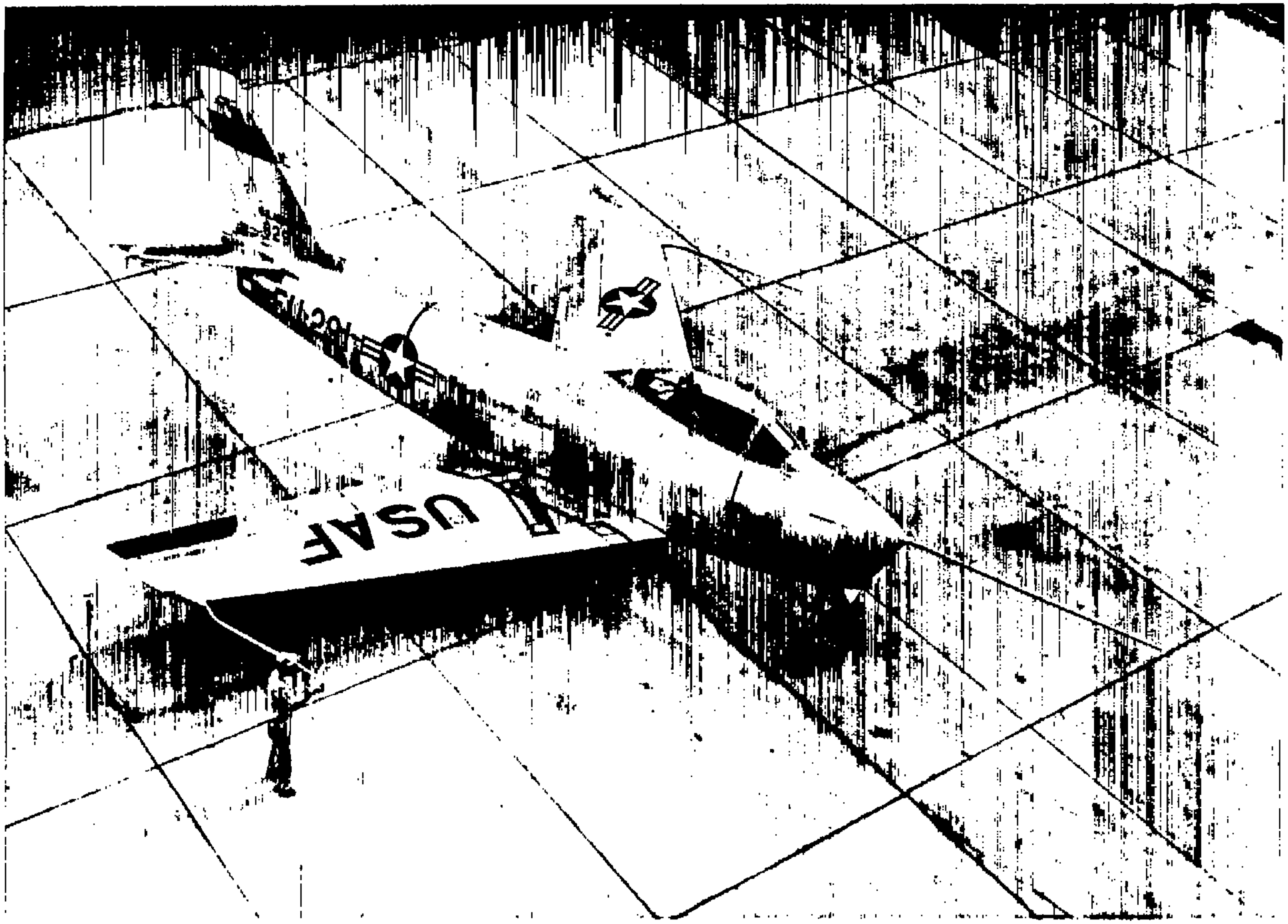


Figure 1.- The test airplane.

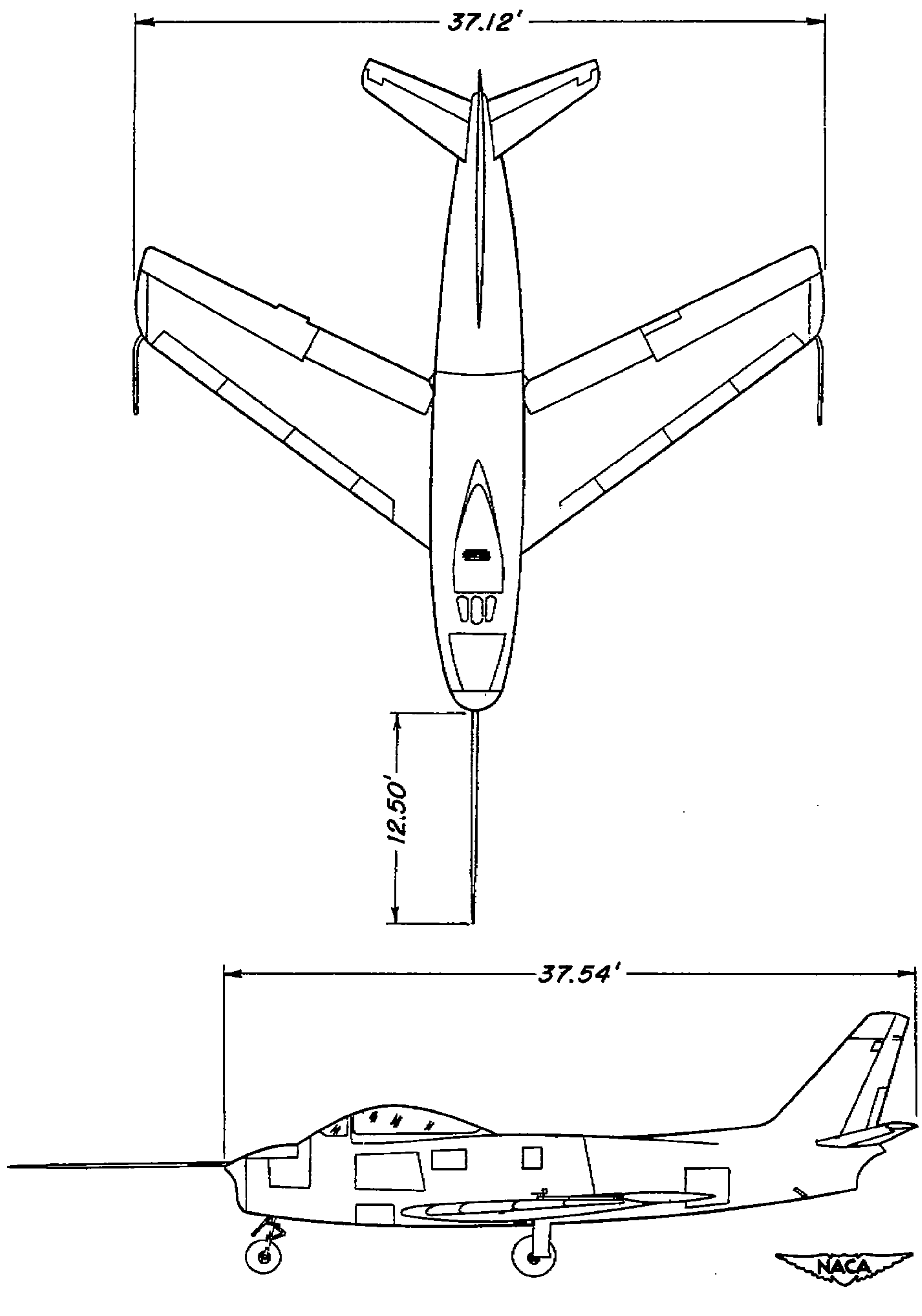
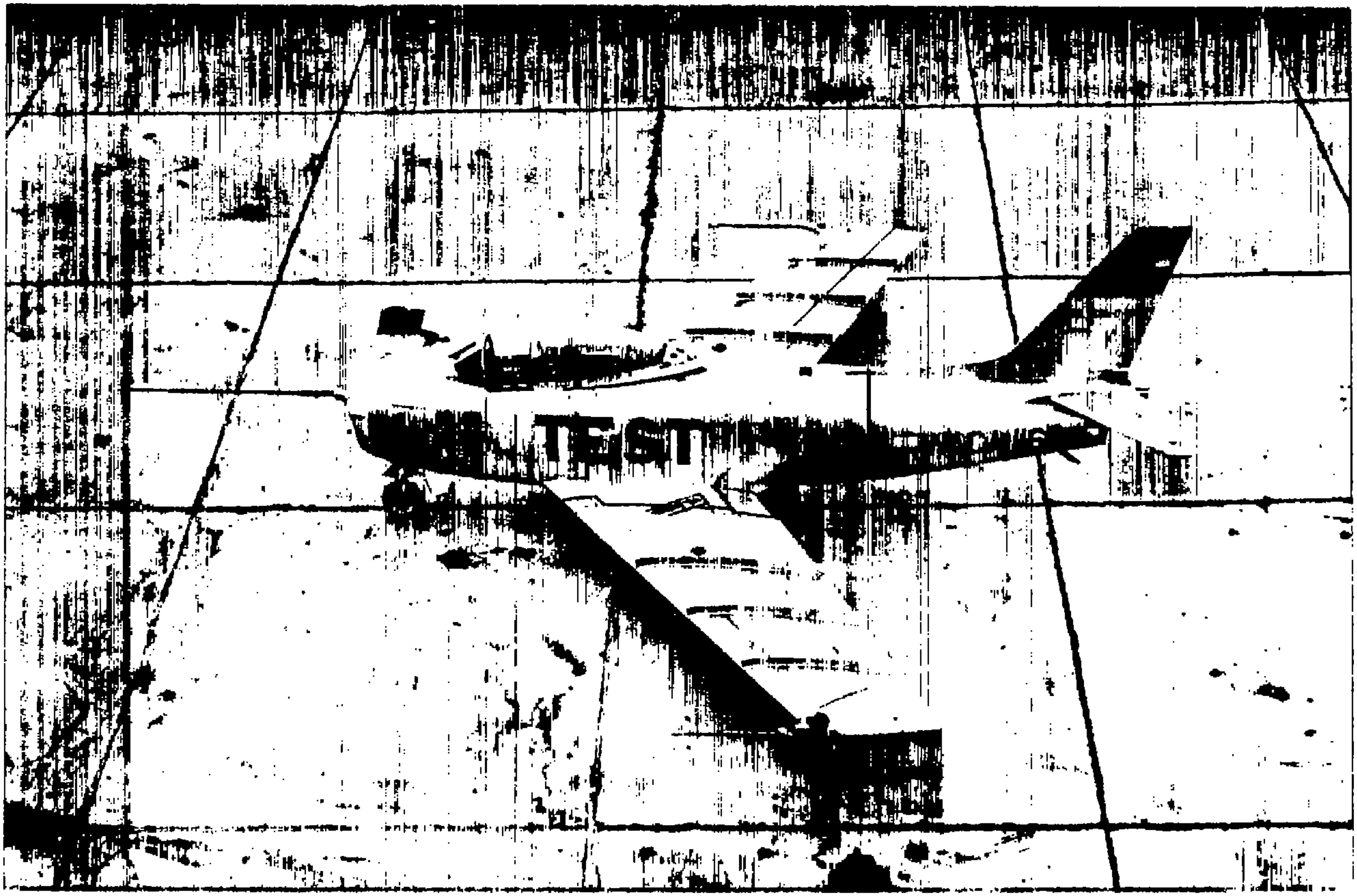
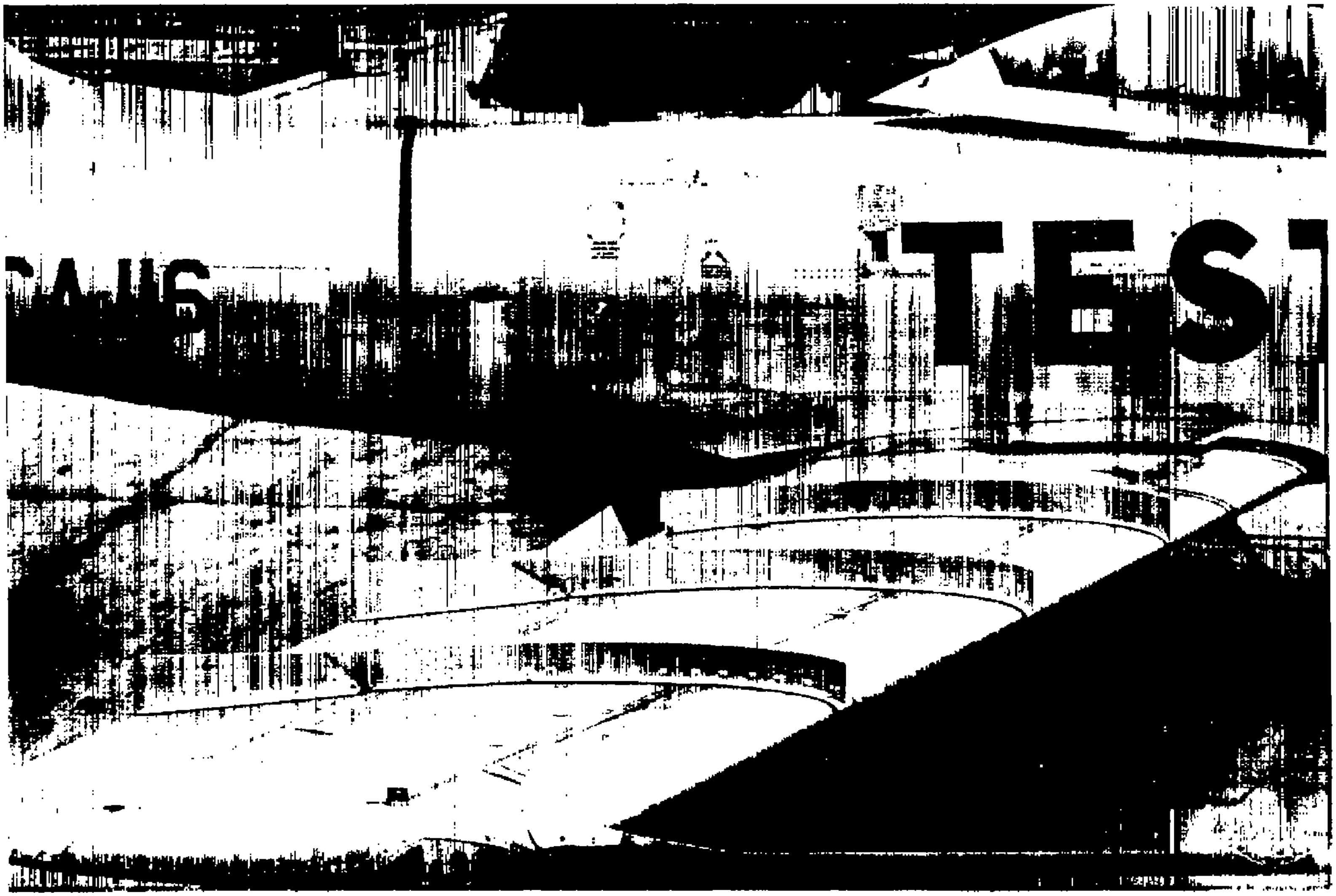


Figure 2.- Two-view drawing of the test airplane.

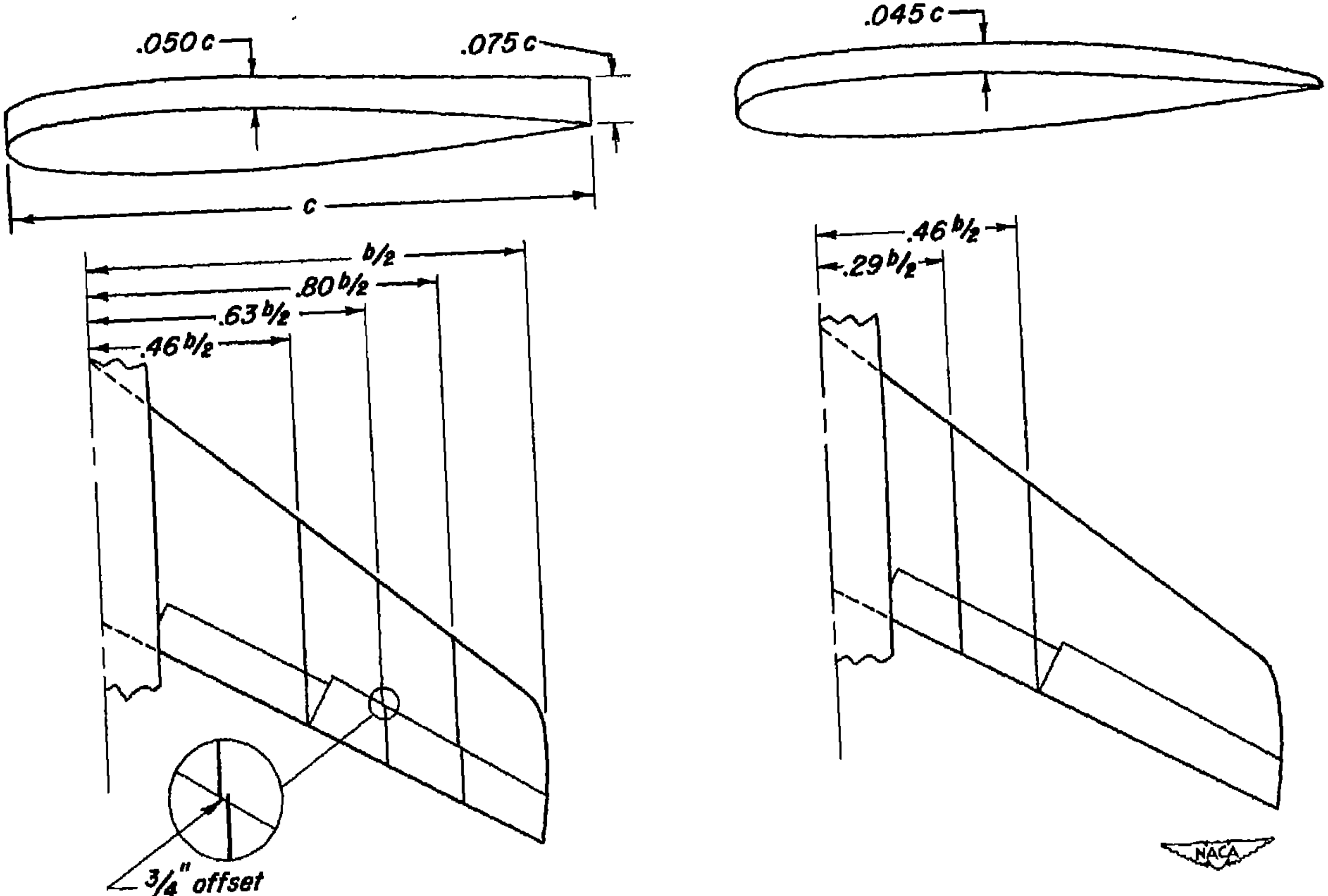


(a) General view.

Figure 3.- Fence configuration A.



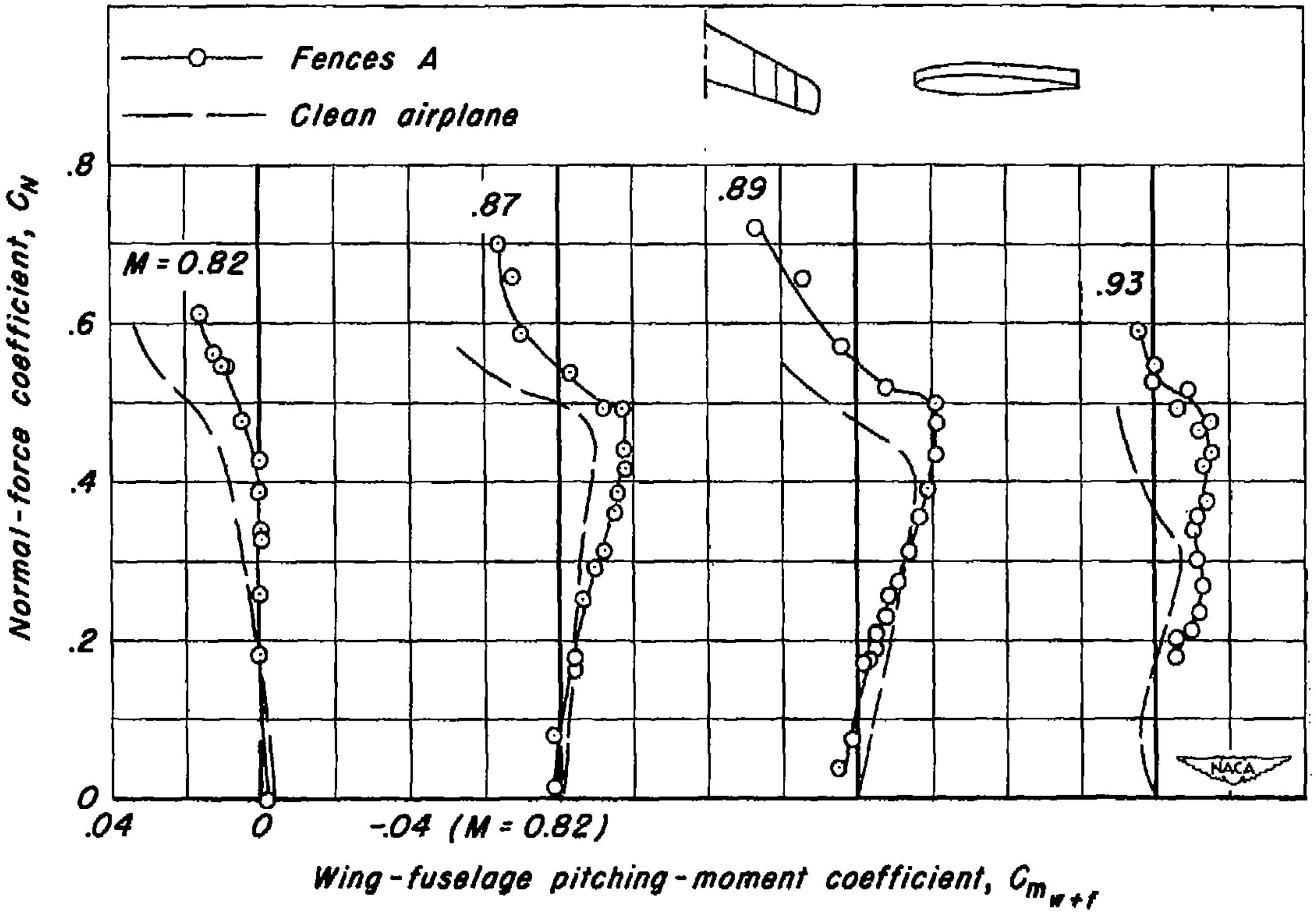
(b) Detail.
Figure 3.- Concluded.



Configuration A.

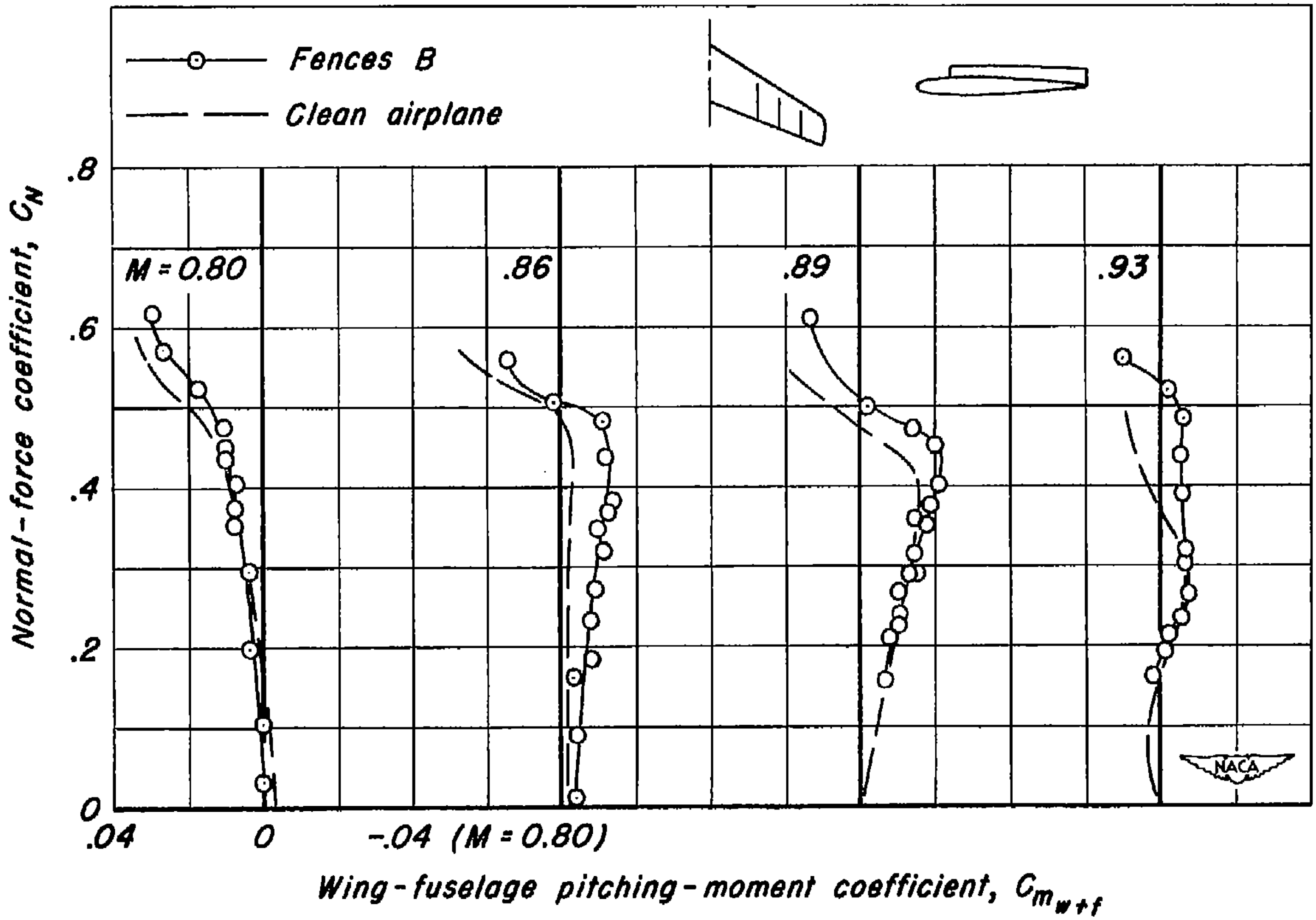
Configuration F.

Figure 4.– Geometric details of basic fence configurations.



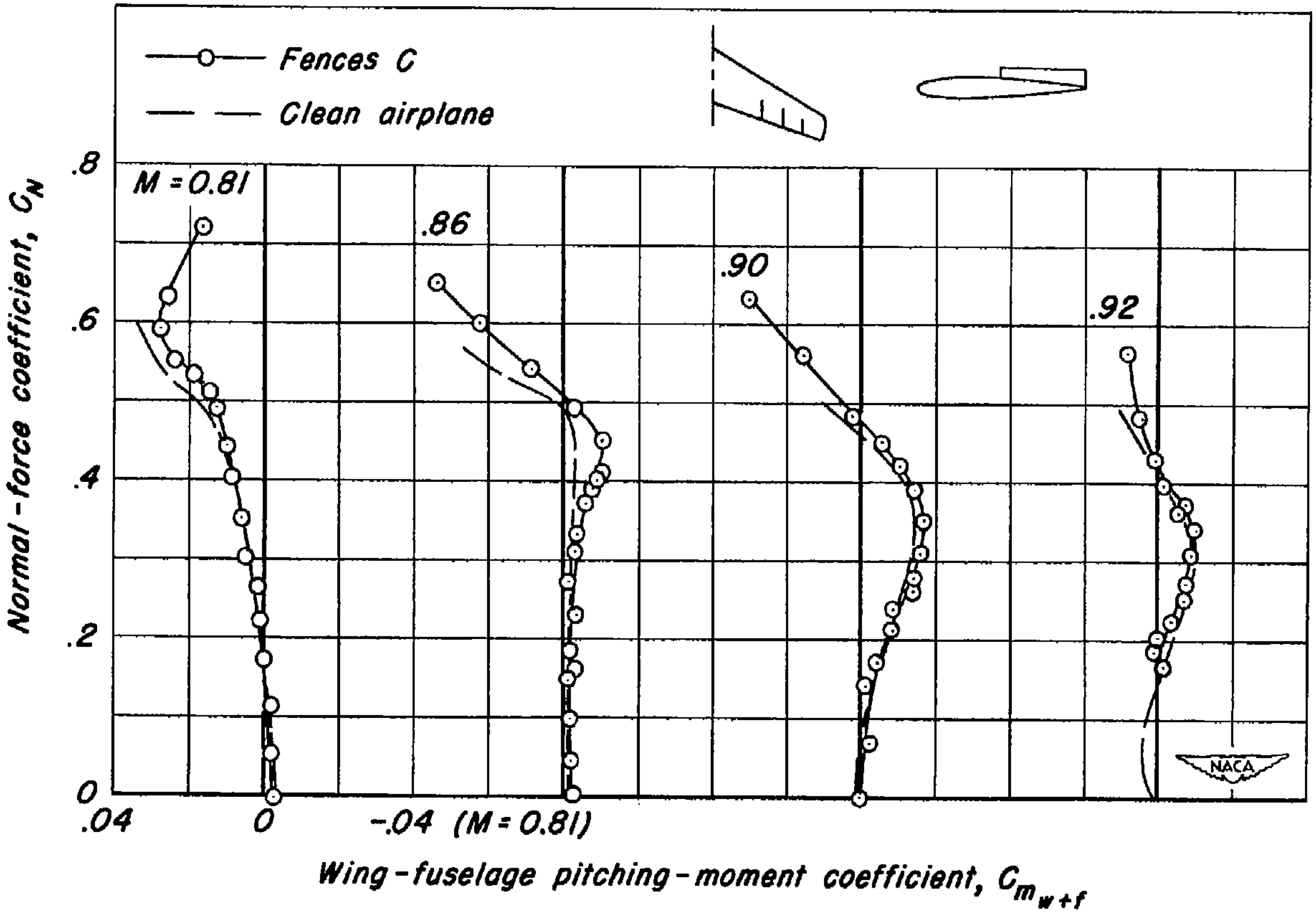
(a) Fences A.

Figure 5.— Variation of wing-fuselage pitching-moment with airplane normal-force coefficient at several Mach numbers with fence configurations varied in chordwise extent.



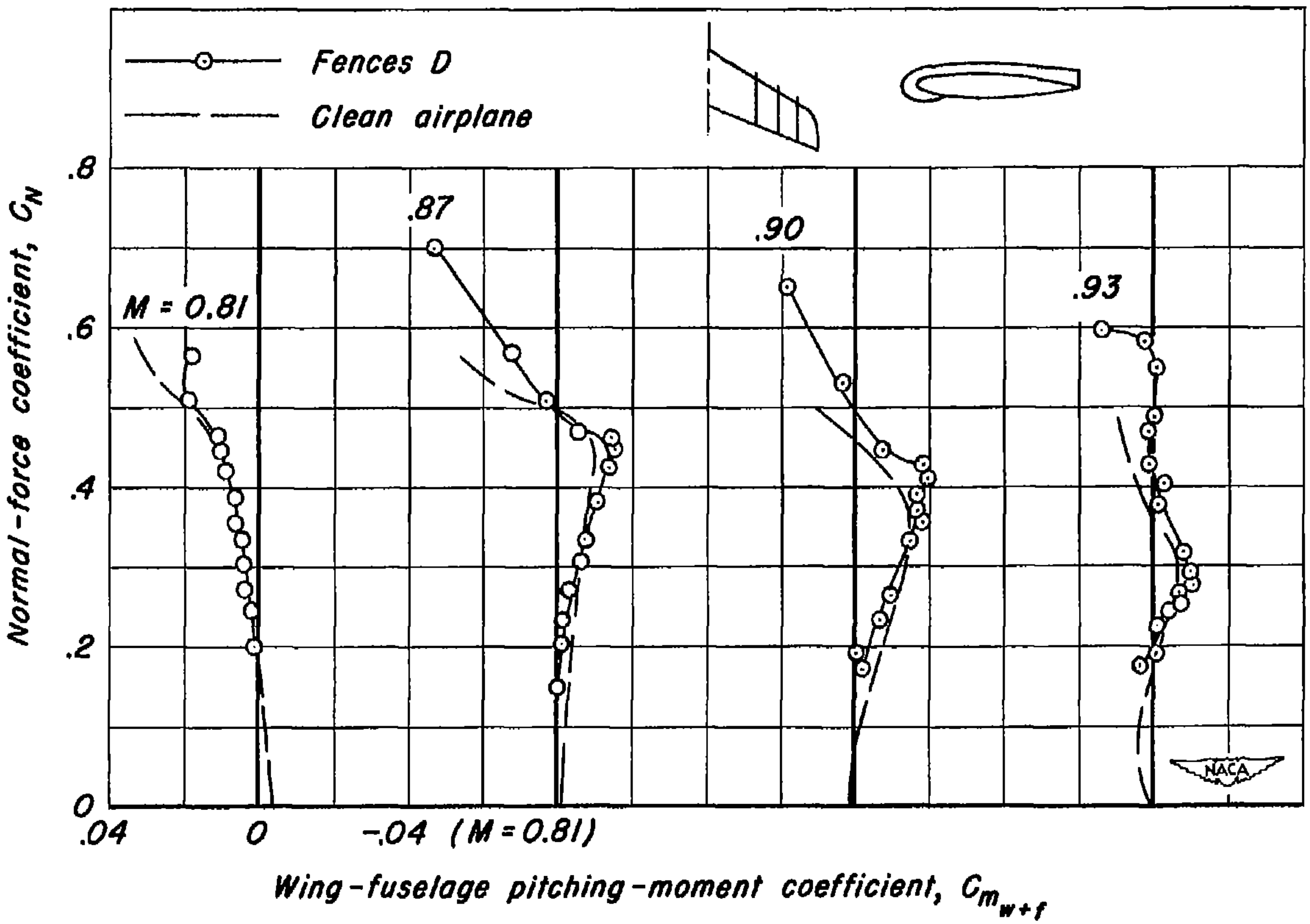
(b) Fences B.

Figure 5.— Continued.



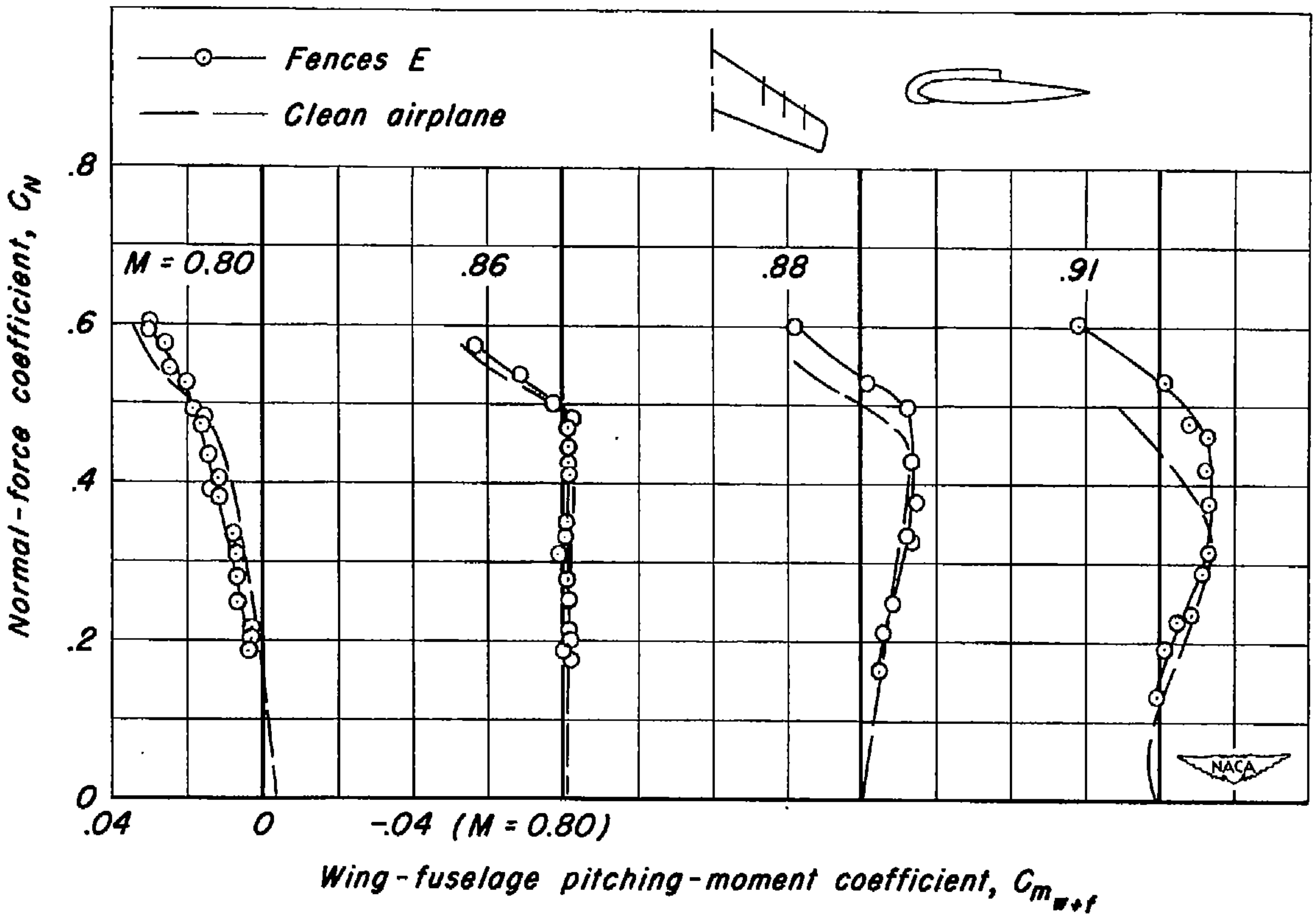
(c) Fences C.

Figure 5.—Continued.



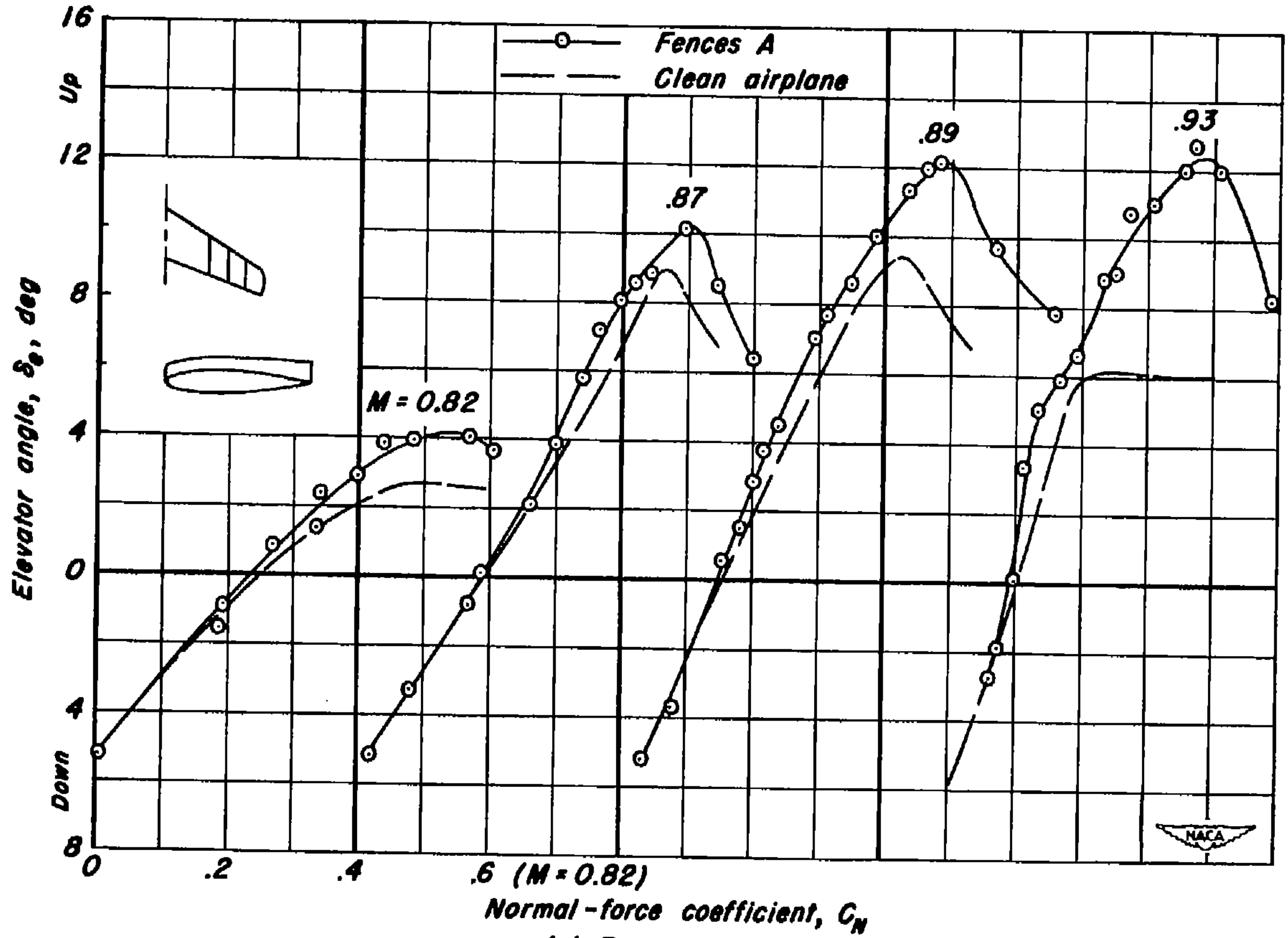
(d) Fences D.

Figure 5.– Continued.



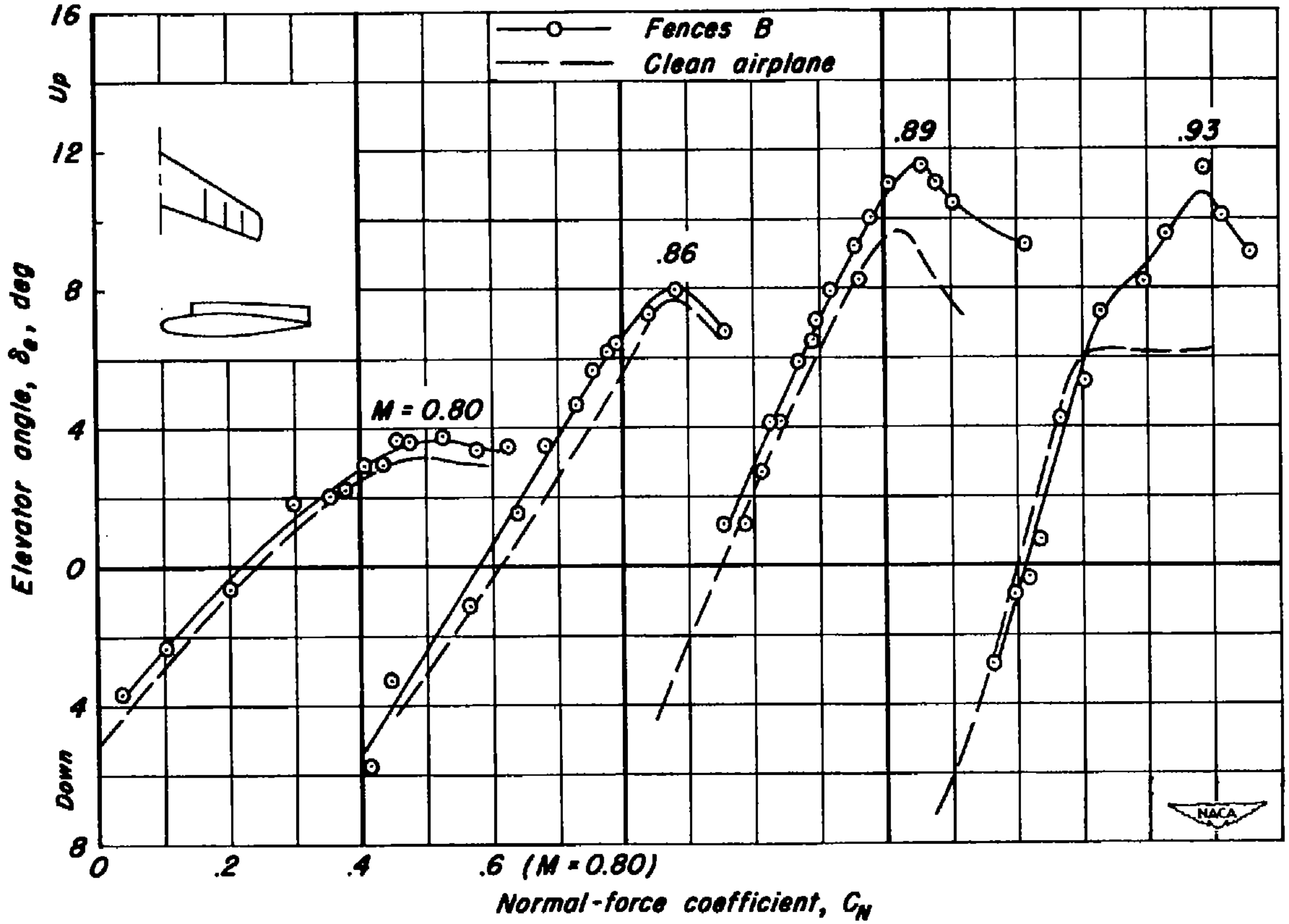
(e) Fences E.

Figure 5.– Concluded.



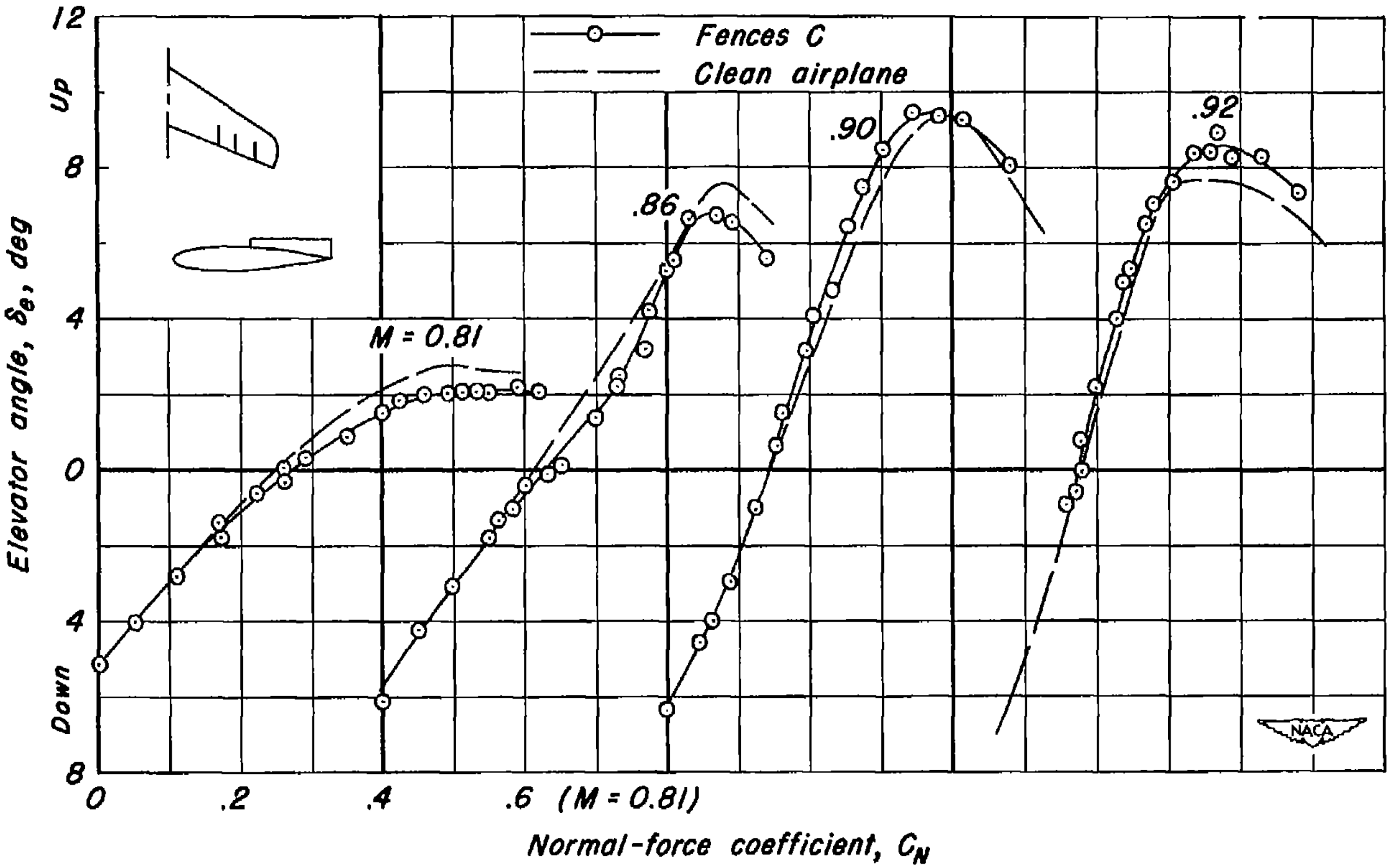
(a) Fences A.

Figure 6.— Variation of elevator angle with airplane normal-force coefficient at several Mach numbers with fence configurations varied in chordwise extent.



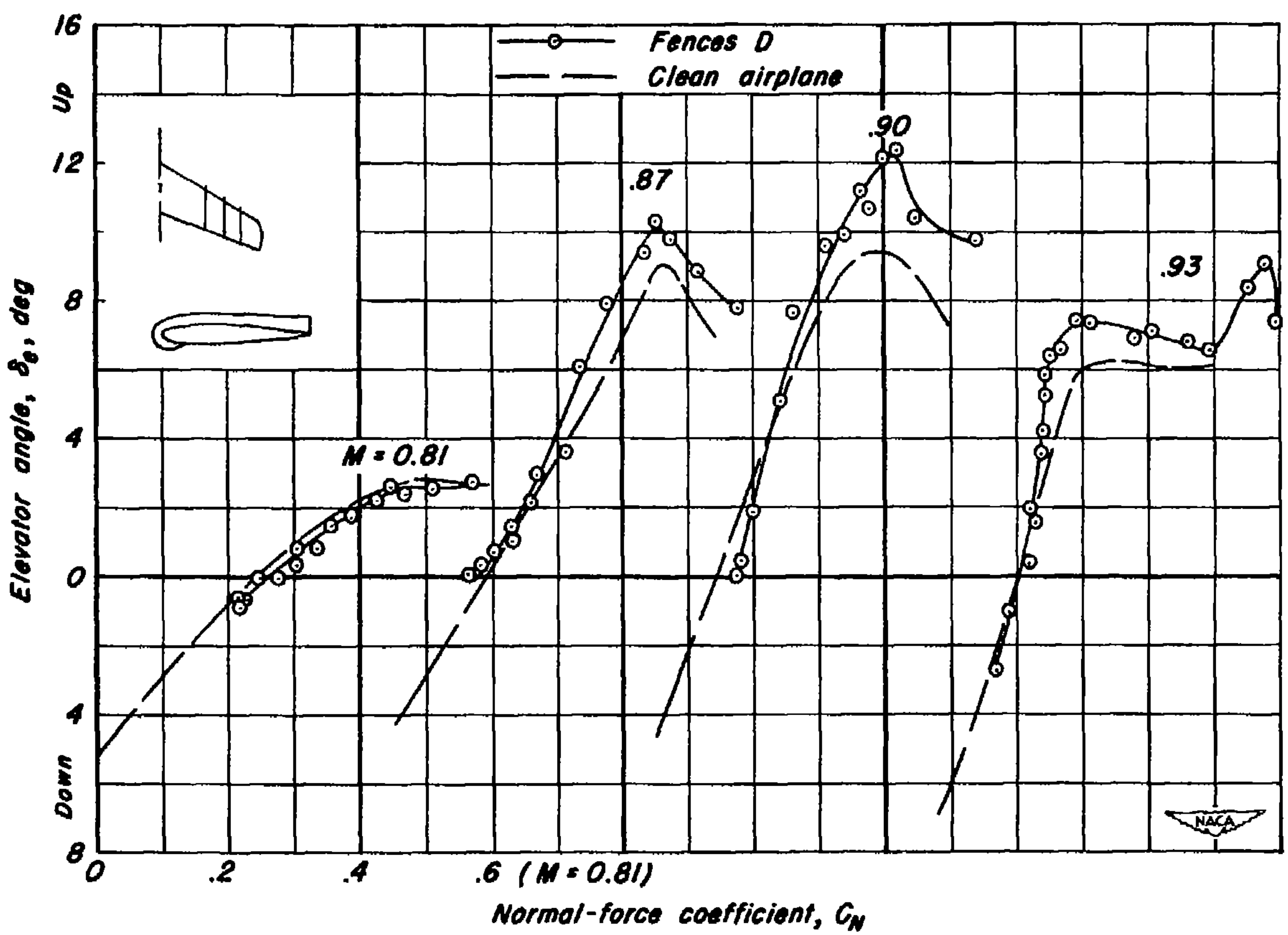
(b) Fences B.

Figure 6.— Continued.



(c) Fences C.

Figure 6.—Continued.



(d) Fences D.

Figure 6.—Continued.

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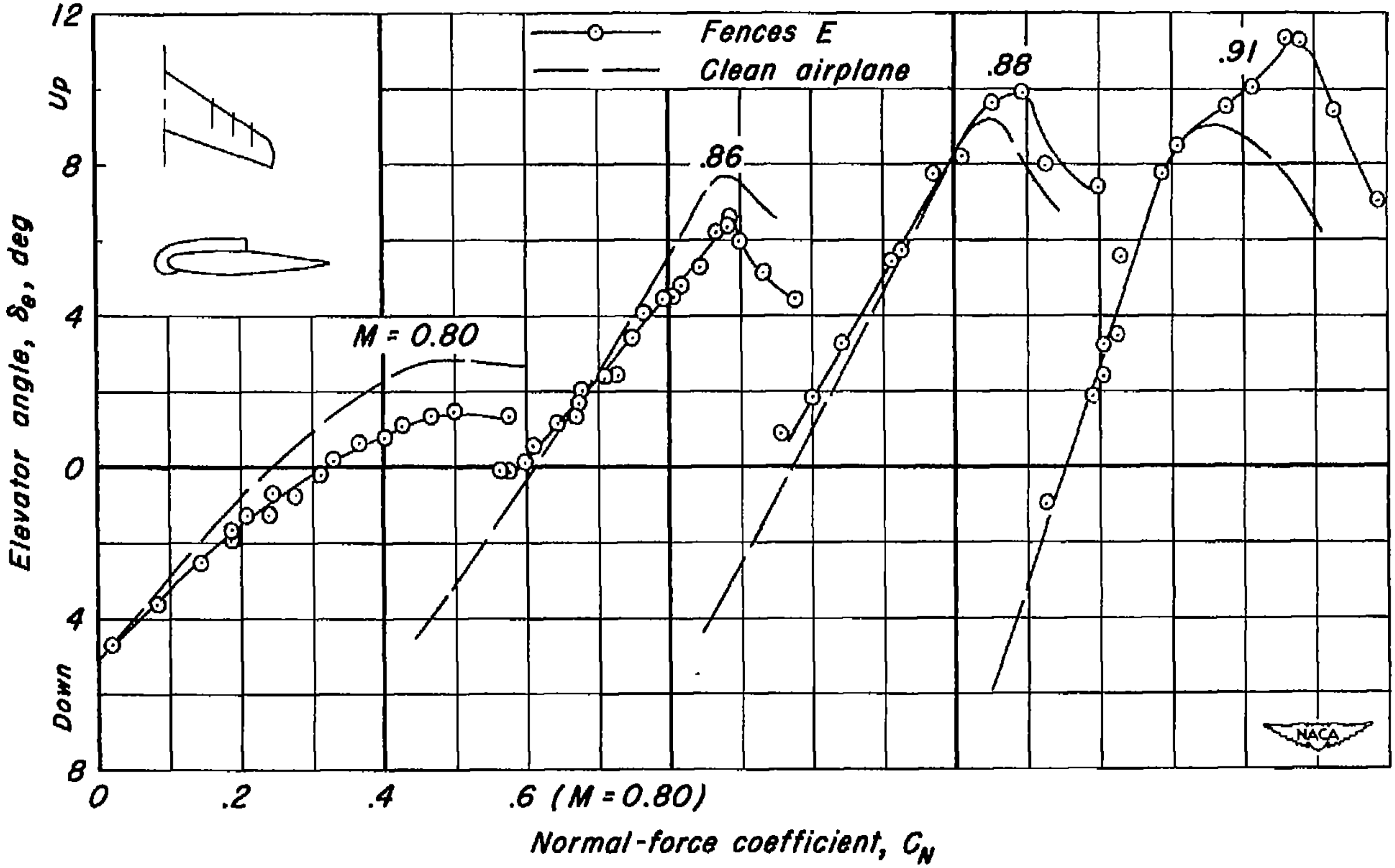

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(e) Fences E.

Figure 6.– Concluded.

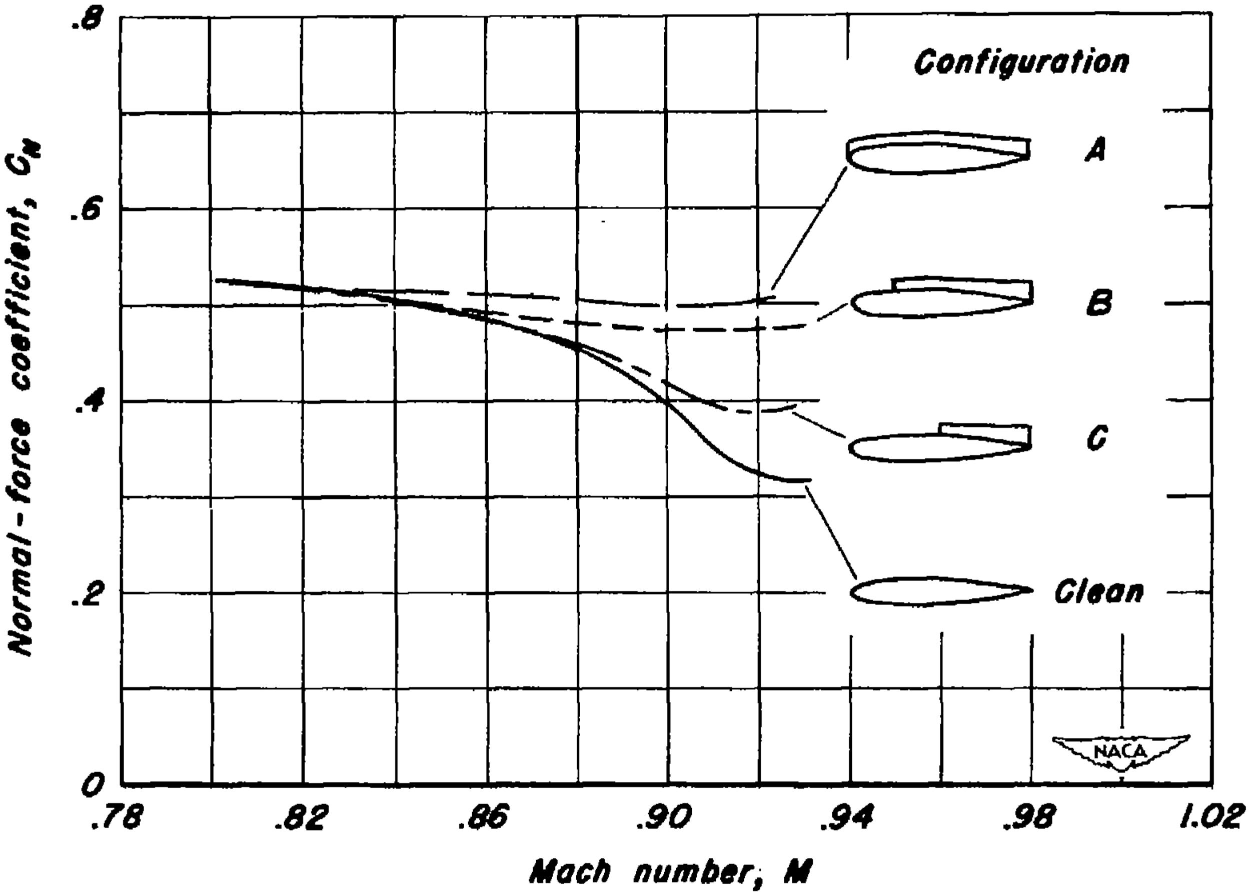
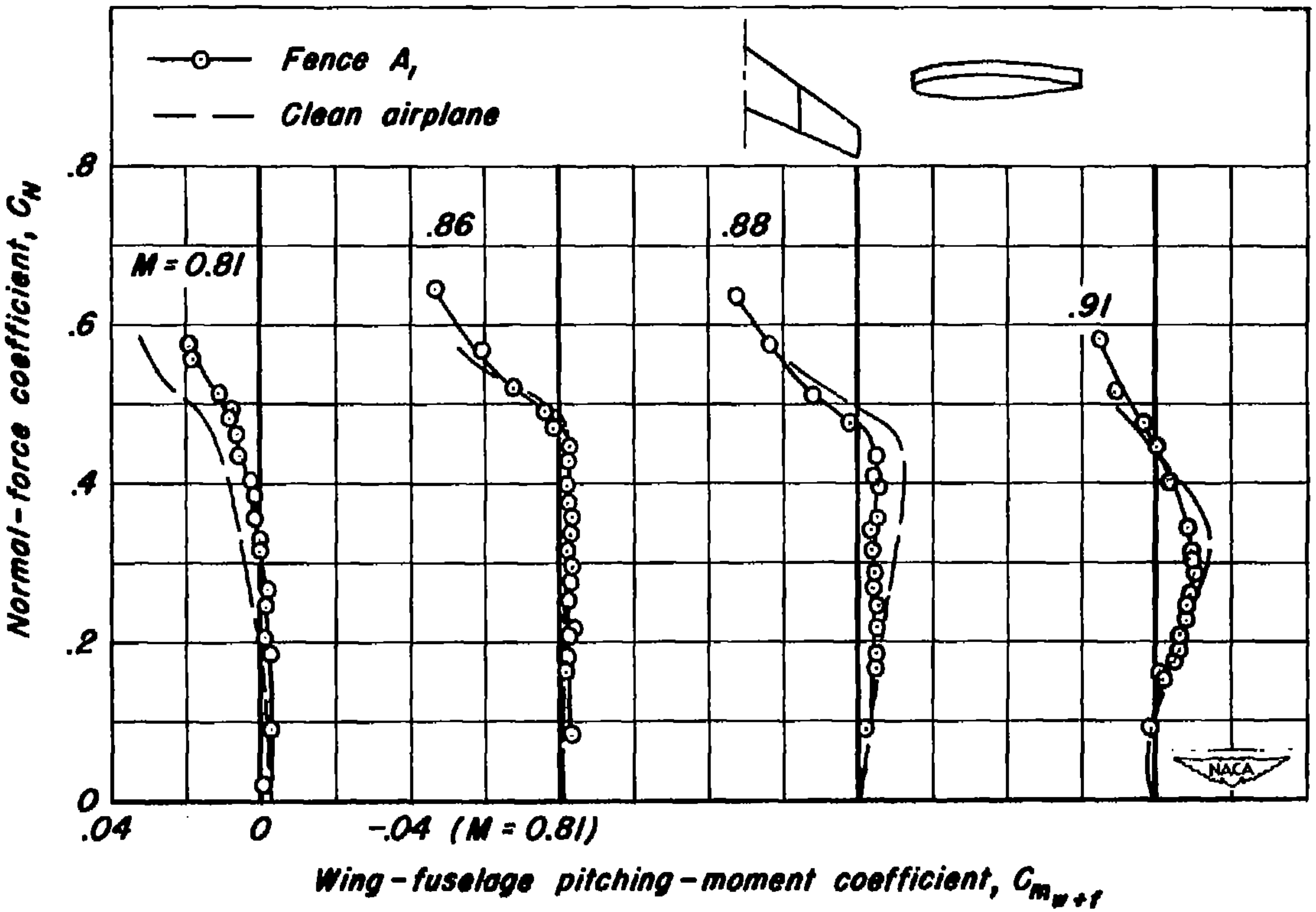
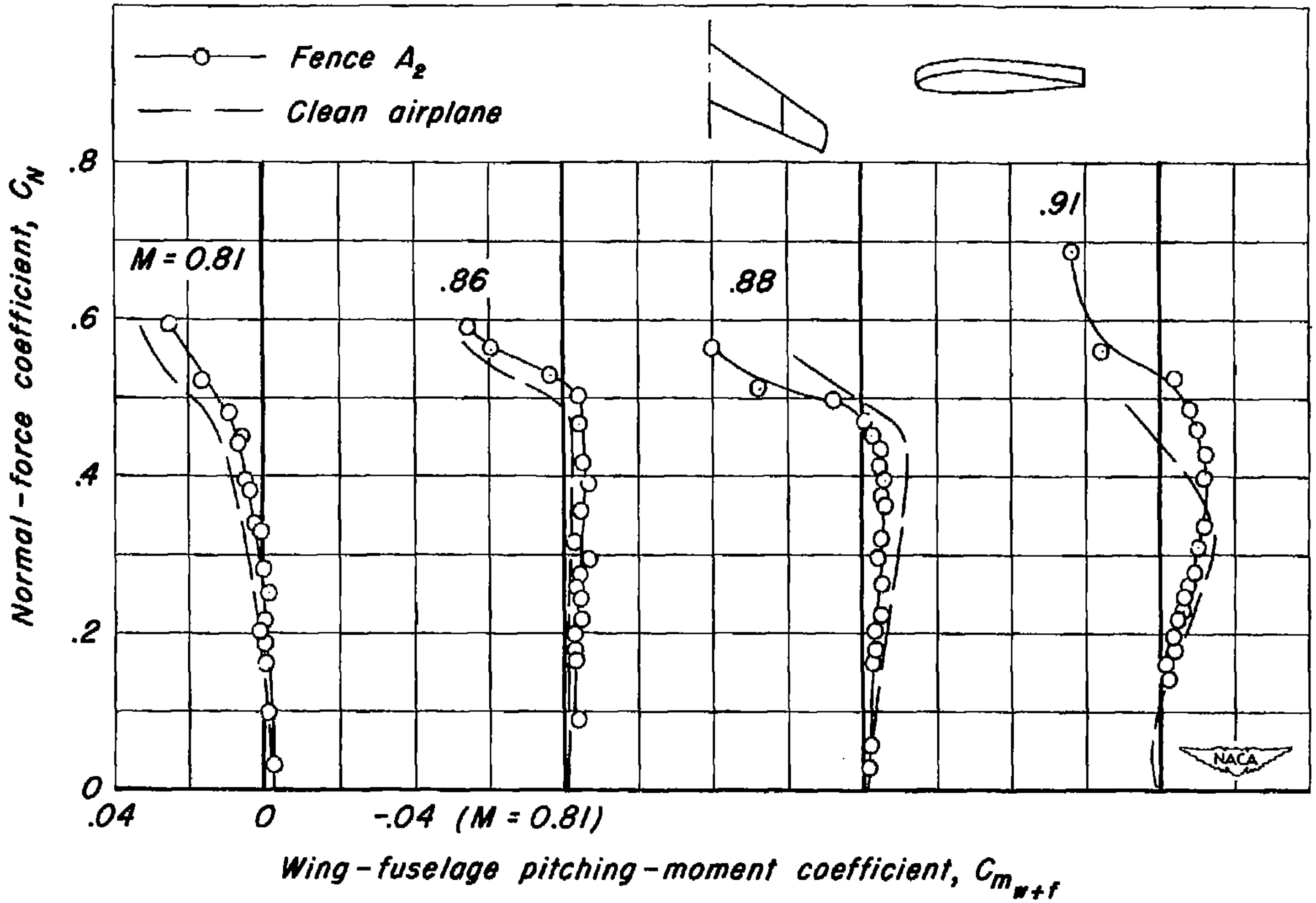


Figure 7.— Pitch-up boundaries of test airplane with fence configurations varied in chordwise extent.



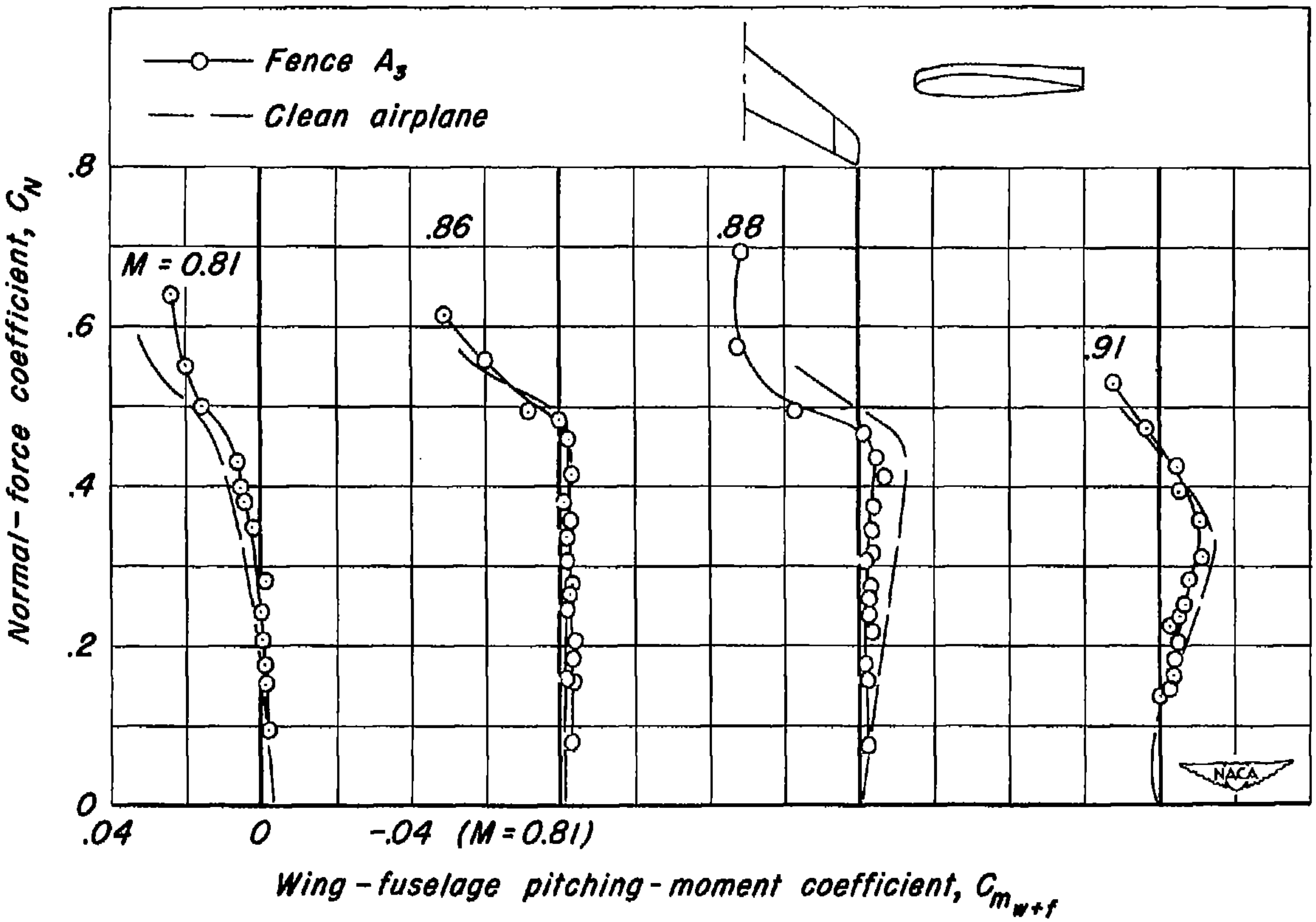
(a) Fence A_1.

Figure 8.– Variation of wing-fuselage pitching moment with airplane normal-force coefficient at several Mach numbers with fence configurations varying in spanwise position.



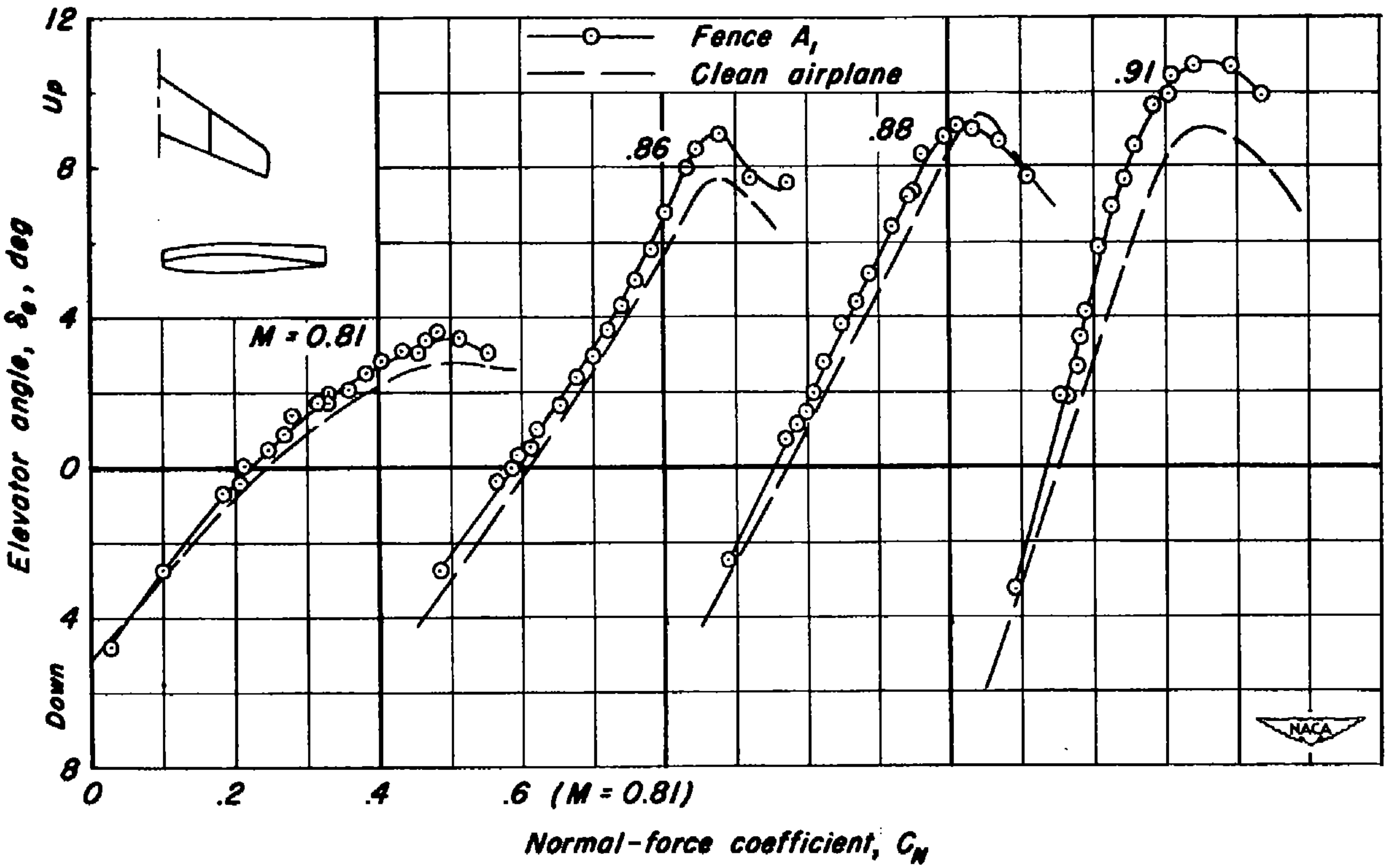
(b) Fence A_2.

Figure 8.— Continued.



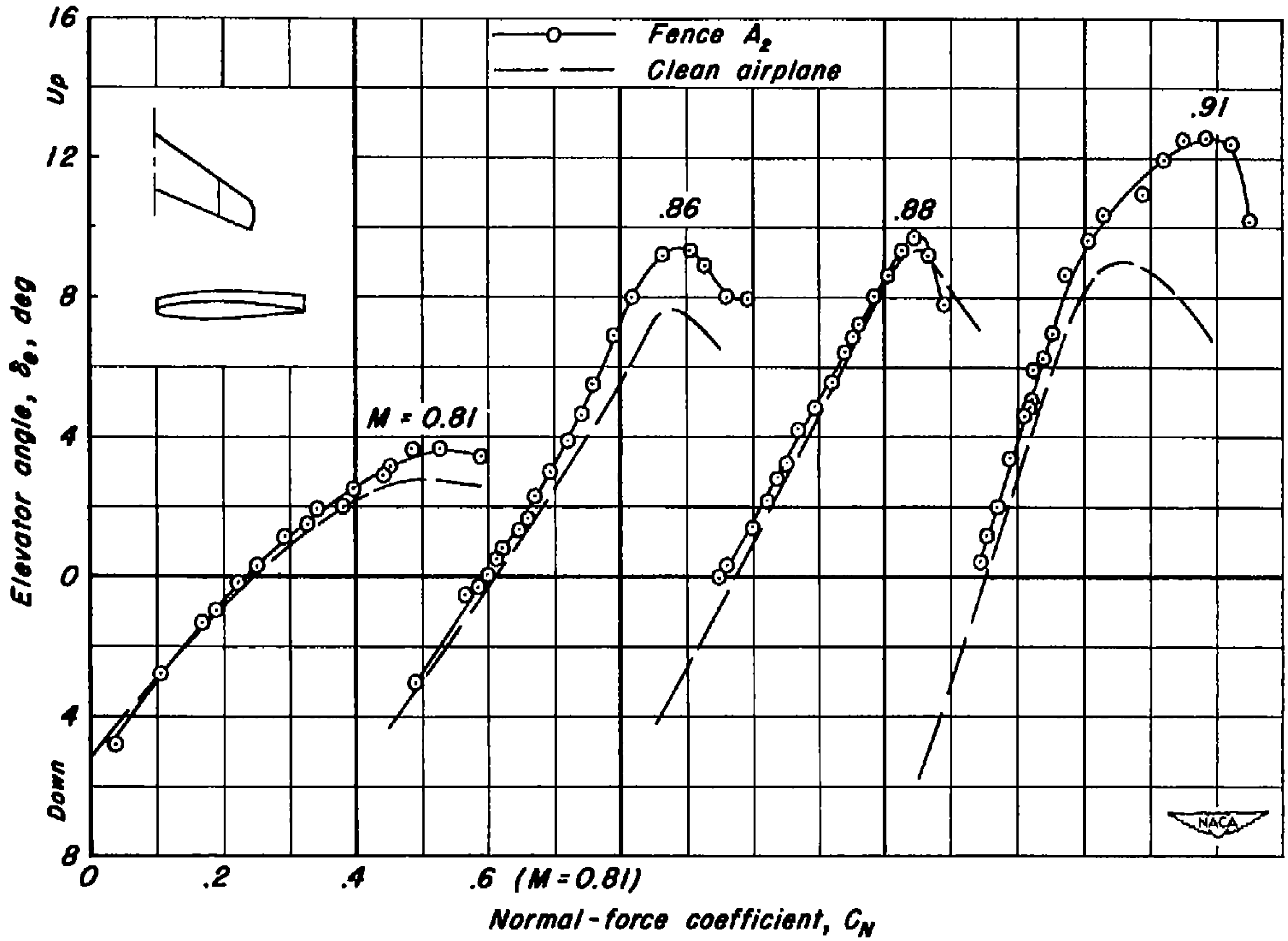
(c) Fence A_3.

Figure 8.— Concluded.



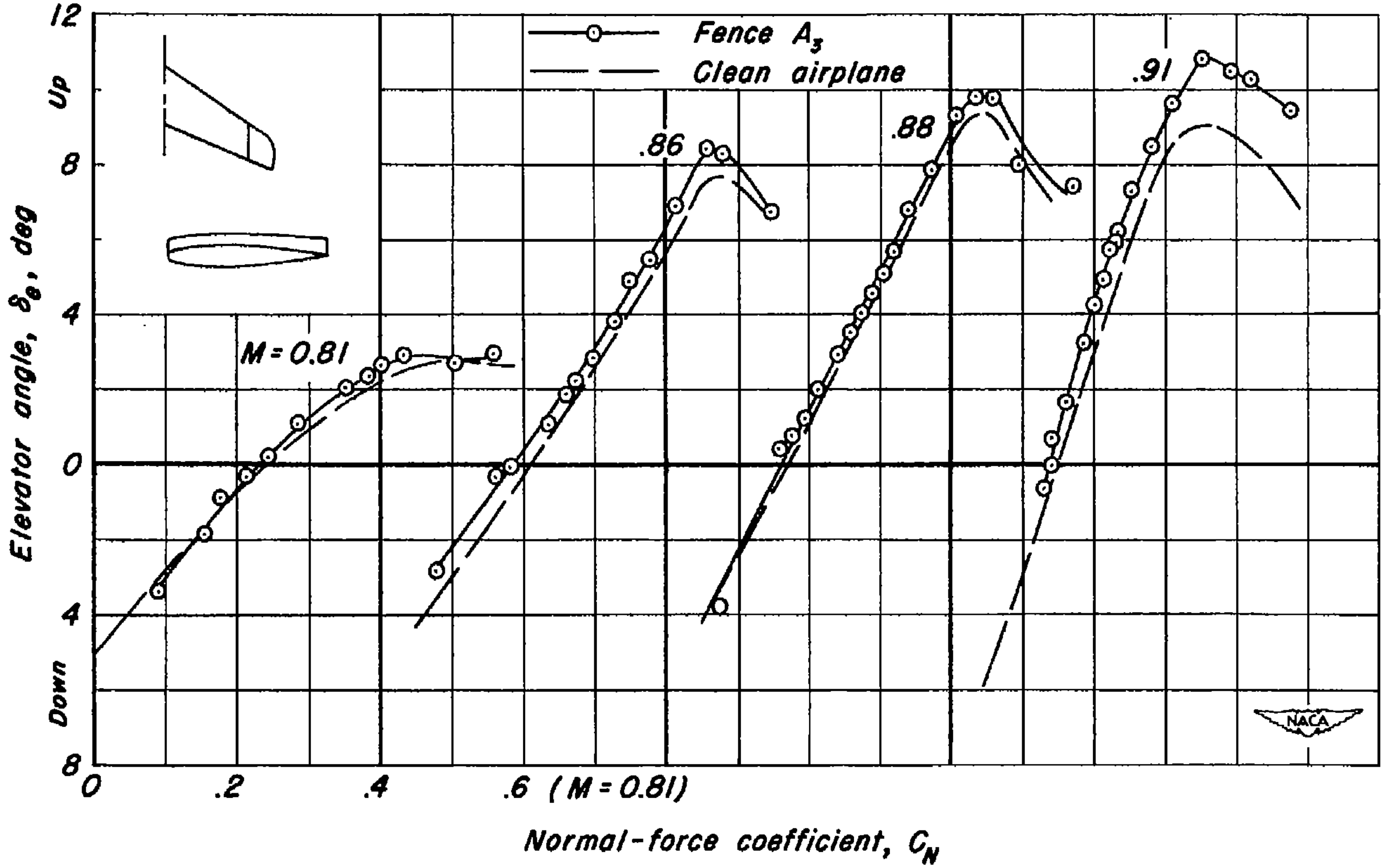
(a) Fence A_1.

Figure 9.— Variation of elevator angle with airplane normal-force coefficient at several Mach numbers with fence configurations varying in spanwise position.



(b) Fence A_2.

Figure 9.— Continued.



(c) Fence A_3.

Figure 9.— Concluded.

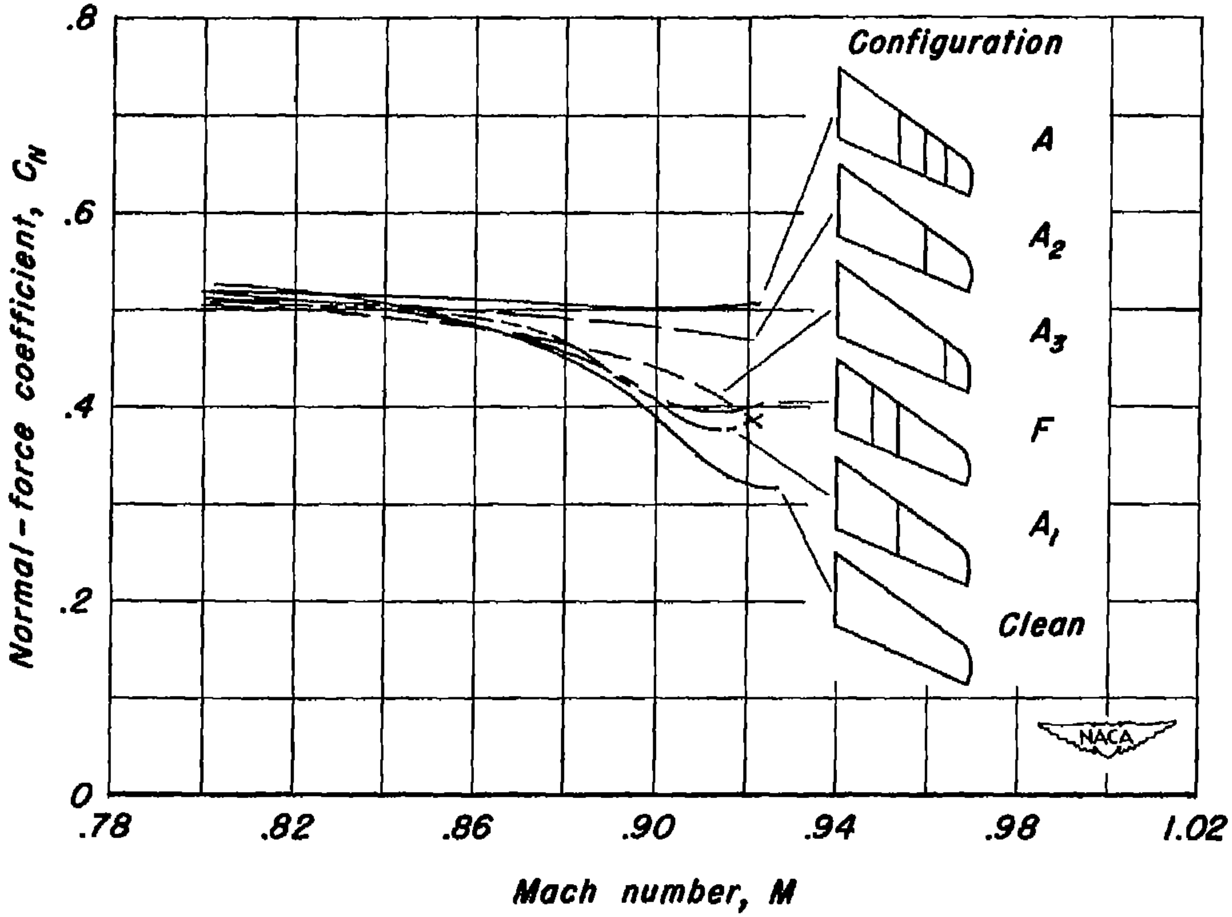


Figure 10.— Pitch-up boundaries of test airplane with fences in various spanwise arrangements.

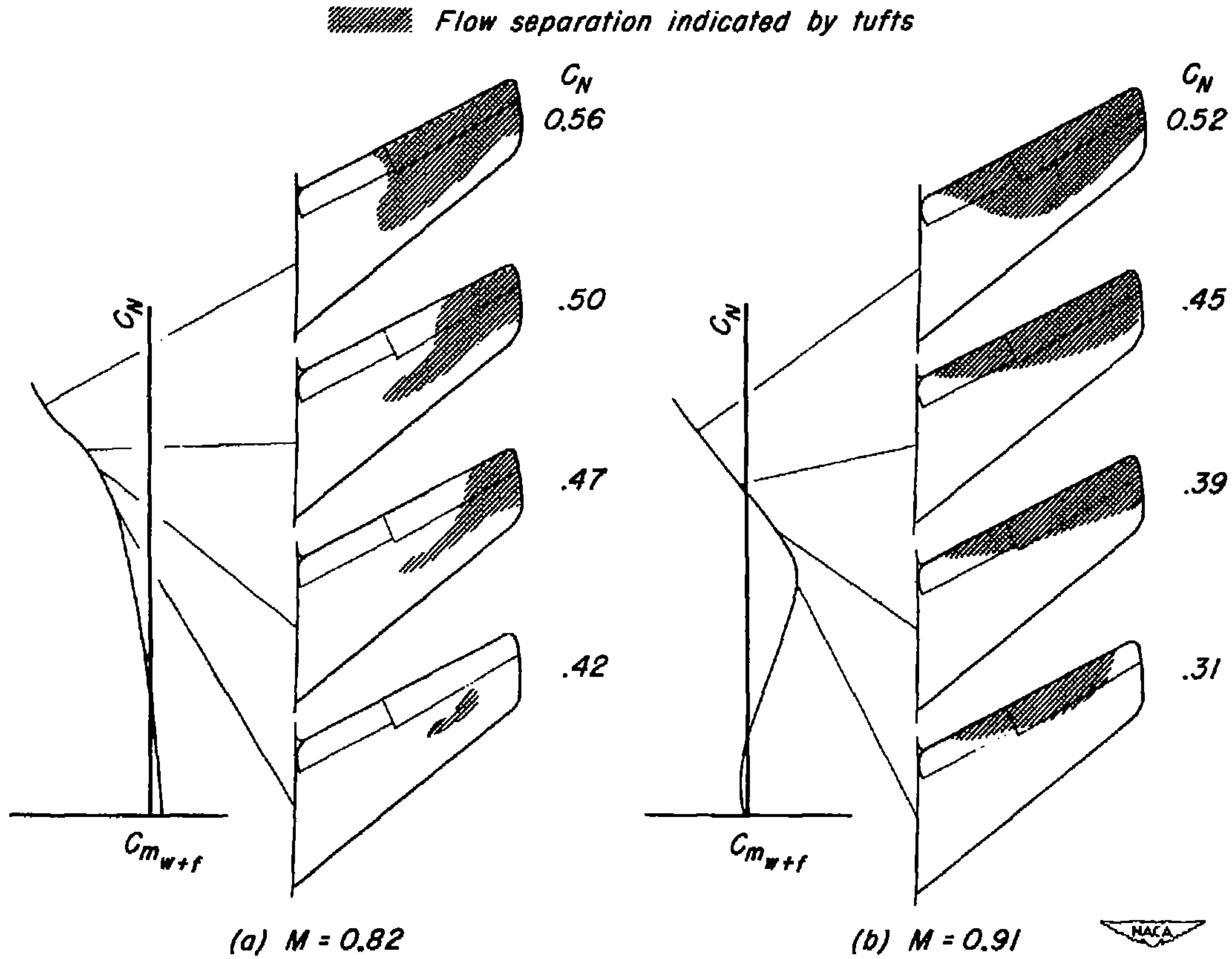


Figure 11.– Flow-separation patterns on unmodified wing of the test airplane as seen in motion pictures of tufts in the wing-boundary layer.

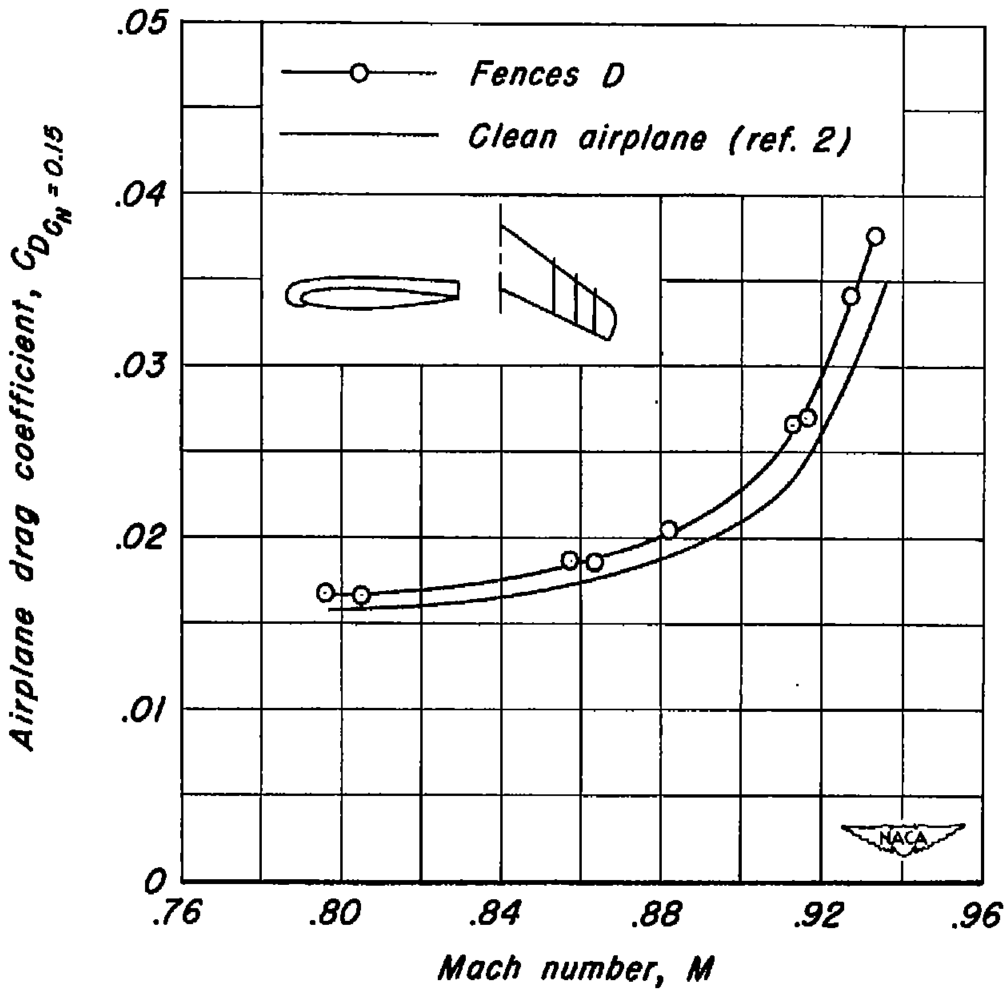


Figure 12.— The effect of a fence installation on the airplane drag coefficient at a normal-force coefficient of 0.15 .

SECURITY INFORMATION

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